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NRX-A6 TEST PREDICTION REPORT

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ABSTRACT

Several preliminary tests and one reactor endurance test are planned on the NRX-A6 reactor at Test Cell "C" of the Nuclear Rocket Development Station in Nevada. These tests have been planned to provide significant development information on the design and operating performance of the test article assembly. This report contains analytical predictions of the behavior of the test article during the planned tests. These predictions will be compared to test data during and after the test in order to establish whether the reactor performs in the expected manner. Included are predictions for normal operation and for emergency shutdown.

1.0 INTRODUCTION

The NRX-A6 reactor will be tested in an upfiring position at Test Cell "C" of the Nuclear Rocket Development Station in Nevada. The demonstration of endurance at rated conditions is the prime operational test objective. The major experimental test objectives are the evaluation of the structural, nuclear, corrosion, thermal, fluid flow, and radiation performance of the NRX-A6 test assembly during all phases of operation.

One test is planned for 60 minutes at rated conditions or until a predetermined loss of reactivity has occurred. However, if required, several runs may be made to complete the prime operational test objective. The tests will be conducted according to the NRX-A6 Test Specification.[1*]

This report contains predictions for the complete series of NRX-A6 tests summarized in table 1-1. The predictions give the expected values of many measured reactor and facility parameters. Through comparison of the predictions with test data, deviations from normal reactor and facility operation may be identified for subsequent detailed evaluation.

Detailed thermal, fluid flow, nuclear, radiation, and geometric design analysis data for the NRX-A6 reactor are available in the Data Book.[2] The digital analysis methods utilized in developing the predictions presented in this report are the same as those previously utilized in the NRX-A1[3], NRX-A2[4], NRX-A3[5], NRX/EST[6], and NRX-A5[7] test prediction reports except for modifications due to reactor design changes and model improvements justified on the basis of test data.

The NRX-A6 feedsystem predictions presented in this report were obtained using the CAM-A6 reactor and feedsystem model described in Reference 8. The reactor model is identical to the models used for NRX/EST and NRX-A5 analog predictions with appropriate changes due to hardware differences and other modifications which have been made on the basis of comparisons with NRX/EST and reactor test data. The feedsystem model consists of a representation of the turbine, pump, heat exchanger, inlet line to nozzle torus, high pressure dewar line and appropriate orifices and valves. The facility controllers which now exist in Test Cell "C" are also simulated.

*Numbers refer to references listed in Chapter 11.

The joint test predictions of the Thermal and Nuclear Design (TND) and the Nuclear Systems Engineering (NSE) departments are presented in this report. All supplements will be issued on different colored sheets as additions, revisions, or deletions to this original test prediction report. A three-ring binder is used for convenience in making these changes. The Emergency Shutdown chapter will be issued as a supplement as soon as the design of the emergency shutdown system is completed.

TABLE 1-1

SUMMARY OF NRX-A6 TEST CONDITIONS AND TEST SEQUENCE

Tentative Experimental Test Plan Number	Test Specification Number	Test	Power	Test Conditions: Flow	Maximum Chamber Temperature - °R
EP-I	II.C.2.a	Initial Criticality	50W*	purge	--
EP-I	II.C.2.a	Control Drum Calibration	100W*	purge	--
EP-II	II.C.2.b	Gaseous Nitrogen Flow Test	1KW	125 lb/sec (max)	Ambient
EP-II	II.C.2.b	Liquid Nitrogen Flow Test	--	10 lb/sec	Ambient
EP-II	II.C.2.c	Neutronic System Calibration Tests	50KW*	purge	--
EP-III	II.C.2.d	Full Power Test	1120MW	71.3 lb/sec LH_2	4090

*The maximum power levels for these tests will be determined by NTO. The power during the corresponding NRX-A5 tests is shown. (see Reference 21).

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2.0 SYSTEMS DESCRIPTION

2.1 Reactor Description

The NRX-A6 reactor consists of a graphite fuel core surrounded by a beryllium reflector assembly. The reflector assembly houses the core lateral support system and the control drums. The core is made up of fuel cluster assemblies which are axially suspended from a support plate. A simulated shield is located above the support plate. The reactor configuration is shown in figure 2-1. A complete detailed description of the NRX-A6 reactor is given in Reference 8. The following subsections present a brief description of principal reactor components and identify major design changes from the NRX-A5 reactor.

A. Core

The basic fuel component of the NRX-A6 reactor is a hexagonal shaped fuel element containing 19 coolant channels. Each channel is coated with niobium and overcoated with molybdenum to provide improved midband corrosion performance for the fuel material. The fuel elements are assembled to form clusters. Each nominal cluster consists of six fuel elements surrounding a central unfueled element. Both the unloaded and fueled elements have identical outside dimensions. All unfueled central elements of the NRX-A6 are externally coated with NbC. The unfueled central elements of the NRX-A5 were uncoated with the exception of those in the first two exterior rows of elements. Each unfueled element contains an Inconel tie rod that is attached to the core support plate to provide axial restraint. Irregular clusters which can contain more than one unfueled support element, an irregular number of fuel elements, and partial unfueled elements are used at the periphery. Filler strips at the periphery complete the cylindrical shape of the core. Pyrofoil strips are used between the filler strips and the peripheral fuel elements to provide a slip plane to reduce friction between these two surfaces during transient operation. A pyrofoil wrapper and pyrographite tiles are used between the filler strips and the lateral support system. In addition, a particle retainer has been added in the dome area of the filler strip to assure that broken particles cannot work their way into the core inlet plenum.

At its aft end, each cluster is connected to the tie rod through a support block. The NRX-A6 uses skirtless support blocks with composite (NbC and carbon) protection cups. The NRX-A5 support blocks had a skirt which extended to the end of the protection cup. Tungsten protection cups are used for the irregular peripheral clusters in which two central unfueled elements are adjacent to each other and for the clusters with exit gas thermocouples.

A statistically designed fuel element arrangement has been incorporated in the NRX-A6 core, using fuel elements fabricated by Y-12 and WNCO. In addition, experimental elements made with various new coating techniques and processes as well as new fuel matrix compositions are included. Also seven LASL clusters with pedestal support are used.

Similarly as in XE-1, twenty-one cluster exit gas thermocouples have been incorporated in the NRX-A6 reactor.

B. Reflector

The reflector consists of three beryllium rings which are stacked to form a cylindrical assembly. In addition to its nuclear function, the reflector is a major mechanical component in that it contains the control drums, houses the lateral support system springs and transmits the axial load from the support plate and reflector to the nozzle flange assembly. The reflector assembly is cooled by hydrogen propellant after it exits from the nozzle tubes. Part of this flow is diverted to the pressure vessel annulus where it cools the pressure vessel and the outer beryllium reflector. In addition, the beryllium reflector consisted of twelve axial segments instead of annular rings.

C. Lateral Support and Seal System

The lateral support system consists of 24 rows of seals. Plunger pins and sleeves which penetrate the reflector inner diameter are held in place against the inner seal segments by helical coil springs seated in the reflector. The inner seal segments in turn translate along the outer seal segments which are seated on the inner diameter of the reflector. Coolant holes are placed in the NRX-A6 seal segments to provide controlled leakage at the core periphery and provide the desired axial pressure profile to insure adequate core bundling.

The NRX-A6 lateral support and seal system is of a different design than previous NRX reactors, but functionally it is the same.

(CRD) D. Core Support Plate and Reactor Support System

The core is axially supported by the core support plate. A total of 289 cluster tie rods are attached to the support plate. The support plate is attached to the beryllium reflector assembly by means of the forward end support ring. The reflector in turn is attached to the nozzle by the aft end support ring. In the NRX-A5 reactor, a dome end support ring connected to the forward vessel flange was used for core support.

(CRD) E. Shield

The domed aluminum shield is similar to previous NRX simulated shields. The simulated shield is cooled by propellant from the reflector outlet plenum. The first pass of the shield is cooled by flow through coolant holes in the shield, annular flow passage around the drum drive shafts which penetrate the shield and by the annulus flow between the shield and the pressure vessel. This flow is mixed in the dome plenum (region between the shield and the pressure vessel dome). The coolant then passes axially through the second pass coolant channels of the shield in the direction toward the support plate. Screens are placed at the aft end of each of the second pass holes of the shield to serve as particle catchers. The NRX-A5 reactor had a single domed screen assembly between the shield and support plate.

2.2 Feedsystem Description

A schematic of the Test Cell "C" feedsystem and the NRX-A6 reactor is shown in Figure 2-2. Liquid hydrogen flows from a low pressure dewar through the turbopump and flow meter. Part of the pump flow is bypassed out of L - 109 in order to maintain a constant ratio of pump flow rate to speed of approximately 0.0038 lb/sec/rpm. This bypass flow enables the pump to be operated in a region of sufficient stall margin. Flow then passes through the pump discharge check valve after which most of this flow passes to the reactor while the remainder flows to the counter-flow hydrogen-water heat exchangers and is used to drive the turbine.

The heat exchanger flow passes through inlet valves H-11 and H-21. The liquid hydrogen is heated to ambient temperature gas in the heat exchangers by heat transferred from the counter-flow water. The exit gas passes through the turbine power control valve H-60. This control valve regulates turbine power. In order to bootstrap or start the system, ambient hydrogen is provided to the turbine through H-53.

The reactor LH_2 flows through venturi LF-10. Downstream of LF-10, a vent valve L-111 is provided for chilling the pump and line during powered startups. Feedline flow is initially bypassed through L-111 and then transferred to L-11 by closing L-111 and opening L-11. Flow through L-11 proceeds to the reactor via flow venturi LF-6.

A high pressure LH_2 dewar in parallel with the normal LH_2 feedsystem is provided for emergency shutdown of the reactor. This dewar has a capacity of 4400 lbs. and has an operational pressure limit of 750 psia. The high pressure dewar system is normally isolated from the main propellant feedline by a checkvalve. The dewar is pressurized by hydrogen through valve X-53 and vented by valve X-161. Six gas bottles are provided for pressure blow-down during an emergency shutdown. On shutdown, the pressurizing valves are closed and dewar flow starts as soon as the main feedline pressure drops below the dewar pressure. Flow to the reactor is maintained by the expansion of the bottle gas forcing flow from the dewar to the reactor.

The gas accumulator system shown by the dashed lines between the turbopump and heat exchangers represents a modification of the Test Cell "C" Feedsystem to prevent a severe reduction in flow during the first second of emergency shutdown. The accumulator is pressurized by back flow of liquid hydrogen through a hole drilled in the check valve. The liquid vaporizes in the uninsulated accumulator and pressurizes it. The accumulator provides a means for sustaining feedline flow after feedline pressure at the accumulator check valve drops below the accumulator gas pressure. Emergency shutdown studies indicate that this gas accumulator system can be quite effective in preventing excessive temperatures in the nozzle tube walls.

Table 2-1 is a tabulation of major system line lengths and volumes used in analysis of the feedsystem.

TABLE 2-1

MAJOR SYSTEM LINE LENGTHS AND VOLUMES

Description	Volume (in^3)	Length (in)
	Main Feedline	
L-11 to nozzle torus	31,324	625
Pump discharge check valve to L-11	47,418	696
Main propellant feedline tee to TES inlet check valve	18,184	700
Pump discharge to L-109 and check valve	3,500	136
	High Pressure Dewar	
Feedline to base of high pressure dewar	41,880	837
High Pressure Dewar	1,880,000	152
Gas Bottles to High Pressure Dewar	8,754	590
One gas bottle	81,216	200*
	Turbine Energy Source	
TES inlet check valve to exit of two active heat exchangers	190,000	4,762**
Two inactive heat exchangers	173,000	4,100
Heat exchanger exit to H-60	48,900	***
H-60 to turbine inlet	2,000	***

* There are six gas bottles piped in parallel.
** There are four heat exchangers, two of which will be used for NRX-A6.
*** Not used in model.

2.3 Controls Description

Reactor flow and pump speed control systems are provided in Test Cell "C" as described in section 2.2 of this report. The speed controller provides the necessary signal to the turbine power control valve to establish a desired speed. If the measured speed is less or greater than the demand speed, the valve will open or close respectively, thus providing the proper amount of flow to the turbine. The flow controller in turn provides the speed demand to the speed controller based upon a comparison between a desired reactor flow rate and a flow rate as measured at flow venturi LF-10.

In order to insure that the Mark XXV turbopump operates sufficiently away from the stall region, a specific speed loop is provided. The function of this control system is to bypass pump flow through the pump vent valve L-109 in order to maintain a constant ratio of pump flow rate to speed. This action provides sufficient stall margin for the turbopump during normal operation.

Controllers are provided for the turbine energy source (heat exchanger) inlet valves H-11 and H-21 which automatically position these valves to obtain the desired pressure drop between the main propellant line and the turbine energy source.

Reactor power and temperature control systems are provided. The power controller adjusts the reactor control drum position to obtain the desired reactor power levels. Control systems are provided for reactor chamber temperature and station 26 temperature control. Both systems provide closed loop signals to the reactor control drums based on errors between measured and demanded temperatures.

Both power and temperature controllers have override circuits (limiters) which are designed to prevent the power and temperature limits from being exceeded should malfunctions occur. These systems produce control drum demand signals capable of overriding normal controller demands.

The relative stability of the above closed loop control systems is given in table 2-2. Predicted gain and phase margins for sinusoidal perturbations are given for two reactor operating conditions -- design and a low flow condition. The gain margin is designed as that factor by which the measured over demand ratio must be multiplied when the phase is 180° in order to produce marginal stability. The phase margin is defined as 180° minus the phase lag between demanded and measured control parameters that occurs at unity gain. This table shows the effect of operating level on the degree of stability of the flow, speed, power, temperature, limiters, and heat exchanger control systems.

A more detailed description of reactor and facility control systems is found in Reference 10.

TABLE 2-2

RELATIVE STABILITY TABLE

	Controller	Gain Margin 20 Log_{10} (Stability Factor) db	Phase Margin degrees (°)	Reactor Chamber Condition Flow (lb/sec)	Reactor Chamber Condition Temperature (°R)
1	Flow and	18	75	71.3	4090
	Specific Speed	10	70	30.0	1700
2	Speed and	>30	80	71.3	4090
	Specific Speed	>30	65	30.0	1700
3	Power	21	75	71.3	4090
		21	75	30.0	1700
4	Temperature	>24	85	71.3	4090
		13	37	35.0	2000*
5	Temperature Limiter	25	45	71.3	4090
6	Power Limiter	8	65	71.3	4090
7	Heat Exchanger Inlet Valves	25	90	71.3	4090
		25	45	30.0	1700

*Temperature controller not activated until 2000°R hold.

NRX-A6 REACTOR CONFIGURATION

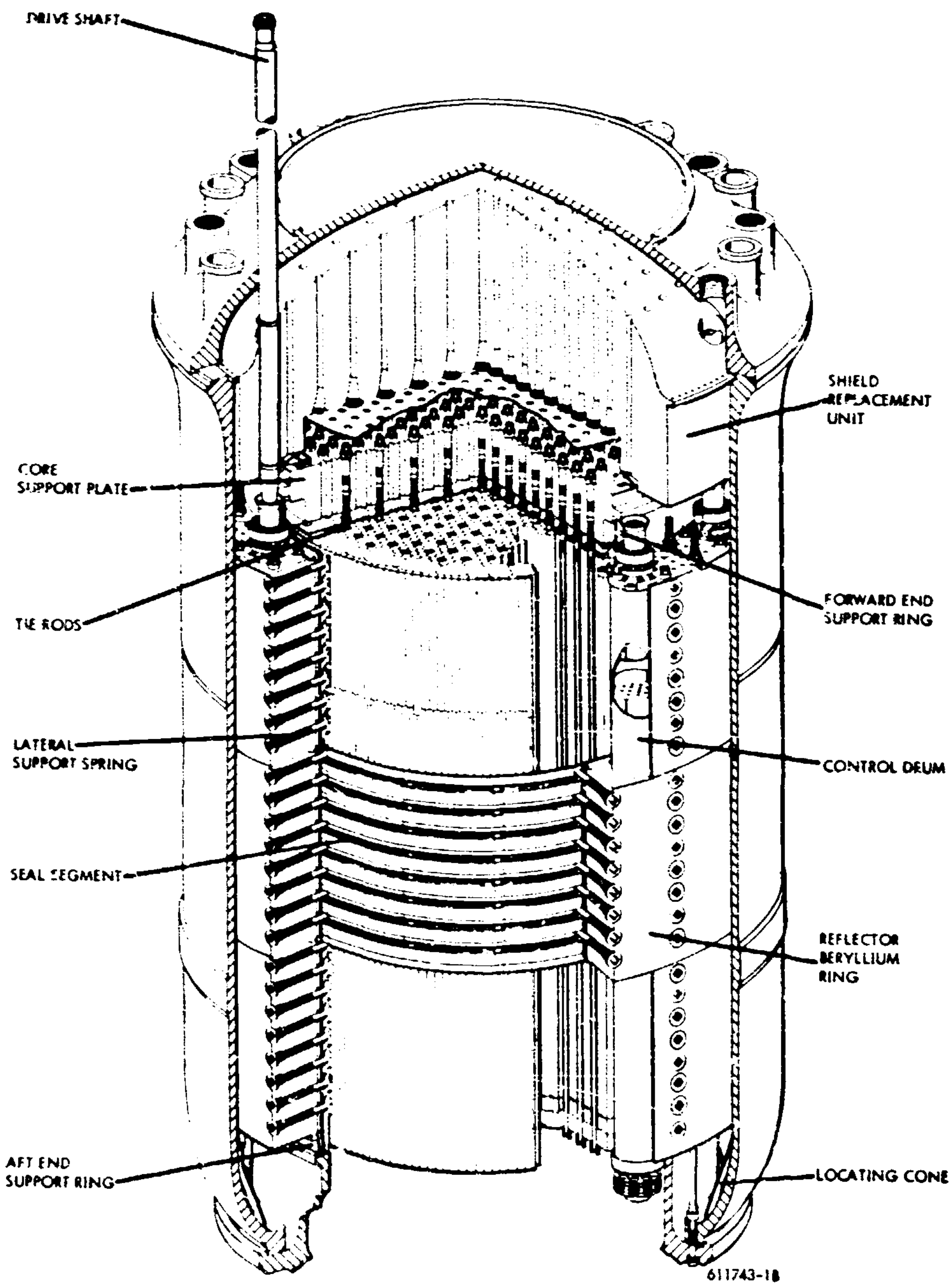

Figure 2-1. NRX-A6 Reactor Configuration

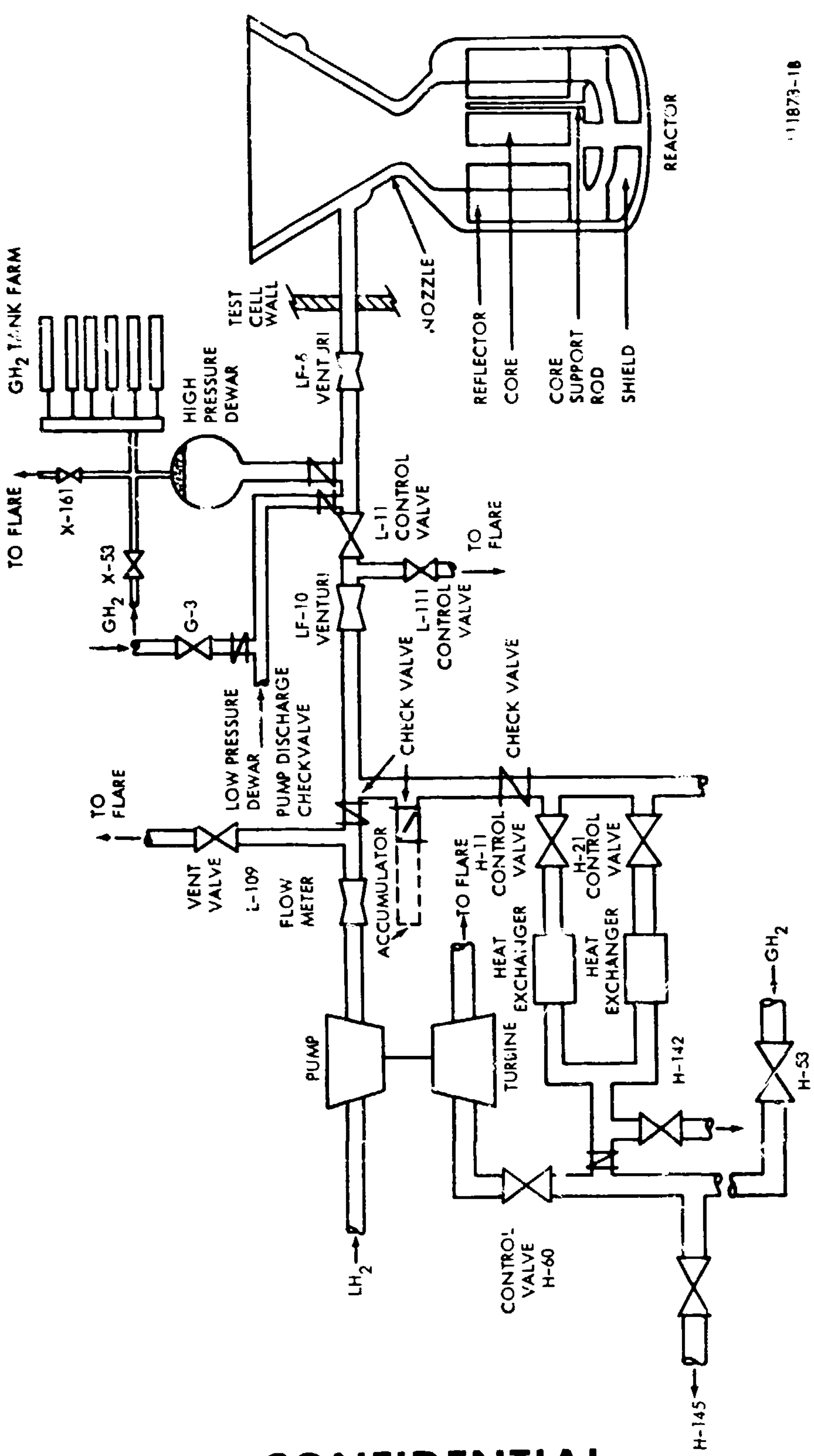

Figure 2-2. Test Cell "C" Feedsystem Schematic Diagram

3.0 LIMITATIONS

The NRX-A6 reactor operating limits are summarized in tables 3-1 and 3-2. These limits were designed to prevent damage to the test article assembly during all phases of test operation. The tables group the limits according to each specific test, and primarily only the limits that may be reached during the test are given. This arrangement simplified the problem of finding which limits are important for the different tests. The limits were taken from the NRX-A6 Test Specification[1]. Any revisions in these operating limits will appear in supplements to the NRX-A6 Test Specification.

TABLE 3-1

NRX-A6 LIMITATIONS: PART 1 - REACTOR TEMPERATURES AND PRESSURES

Parameter	Nuclear Tests	Gaseous Nitrogen Flow Test	Full Power Test	Cooldown	Emergency
TEMPERATURES (°R)					
Outer Reflector Tie Bolt	750	---	---	750	750
Support Plate	830	---	---	830	830
Maximum Initial Outer Reflector	---	---	550	---	---
Average Tie Rod Material	1600	---	1200	1600	1600
Any Core Station with Air Cooling	800	---	---	800	800
Core Station 20 or 26 with Nitrogen Cooling	1400	---	---	1400	1400
Any Core Station with Poison or Au Wires	645	---	---	---	---
Core Station 1	---	---	950	950	950
Core Station 26 (avg.)	---	---	3990	3990	3990
Nozzle Chamber (avg.)	---	---	4290	4290	4290
PRESSURES (PSIA)					
Nozzle Torus	---	1050	1050	1050	1050
Nozzle Chamber	---	600	600	600	600
PRESSURE DROP (PSI)					
Core	---	150	150	150	150

TABLE 3-2

NRX-A6 LIMITATIONS: PART 2

Parameter	Units	Nuclear Tests	Gaseous Nitrogen Flow Test	Full Power Test	Cooldown	Emergency
Minimum Period	sec	0.3	0.3	0.3	---	---
Minimum Shutdown Reactivity	$	2.0	2.0	2.0	2.0	2.0
Maximum Fixed Power Level	KW	(1)	(1)	(1)	---	---
Floating Power Scram Factor, Minimum	---	2.0(2)	2.0(2)	2.0(2)	---	---
Minimum Rod Hydraulic Systems Pressure	psig	400	400	400	---	400
Minimum Servo-Hydraulic Pressure	psig	1600	1600	1600	---	1600

(1)Two times planned power (max.). The estimated power for these tests is shown in table 1-1.

(2)Factor of 2 (measured/demand), may be bypassed above 100 MW.

4.0 INSTRUMENTATION

The NRX-A6 reactor and test cell instrumentation is described in this section. Reactor instrumentation (based on the NRX-A6 Measurement Requirements List (MRL) dated 22 March 1967) is listed in table 4-1. Selected facility instrumentation (based on Test Cell "C" Channel Titles List dated 14 February 1967) is listed in table 4-2. These lists are included for the convenience of the reader and are current as of the indicated dates. Reference should be made to the latest NRX-A6 MRL or Test Cell "C" Channel List for any changes.

Figures 4-1 through 4-12 are sketches showing the reactor measurement locations in relation to each other and to the reactor. Detailed drawings of thermocouple installations will be included in a supplement to this report. Figure 4-13 is a simplified schematic of the Test Cell "C" flow system, showing the location of selected facility instrumentation. The detailed liquid feedsystem is shown in figure 2-3.

CODING FOR MEASUREMENT REQUIREMENTS LIST

Measurement Channel

The first letter designates the system:

A	Test Article	N	Nitrogen
G	Gas Propellant and Inerting	Q	Gas Storage
H	Turbine Drive and Pump	S	Neutronics
I	Instrumentation Function	X	High Pressure LH_2
K	Cooldown LH_2	Z	Rod Actuation
L	Propellant LH_2		

The second letter designates the type of measurement or channel function:

A	Acceleration, Vibration	N	Radiation
B	Binary Indication	P	Pressure
C	Command	Q	Speed

D	Displacement	R	Position Indication
F	Flow Measurement	S	Strain
H	Voltage	T	Temperature
I	Current	V	Control Point Originated
L	Level	[illegible]	Torque
M	Miscellaneous		

The three-digit number designates the specific channel and indicates where the signal originates. For static pressure measurement, this is an even number; for differential pressure measurement, this is an odd number.

The three digit number may be followed by a letter which gives additional information about the measurement:

A	Auxiliary Channel	N	Narrow Range
D	Differential (Pressure)	R	Radial
F	Summary	S	Selected Channel
H	Hoop (Stress)	T	Tangential
I	AC Coupled	U	Analog
K	Digital	W	Wide Band
L	Longitudinal or Low Leg (Differential Pressure)	Z	Zero Suppressed

Following the dash, the digit 6 indicates an NRX-A6 test article channel and the letter C indicates a Test Cell C facility channel. The last letter, if used, provides information on averaging circuits:

A	Input to an average
*	Alternate input to an average

Location

Sta: Station (inches) with zero at inlet end of core elements, positive toward core exit.

Rad: Radius (inches), from core centerline.

Theta: Angular position (degrees), zero through the center of Control Drum One and positive in the counterclockwise direction looking toward core exit.

Set-Up Range

This is the range of measurement over which data are to be taken.

System Bandwidth

For the wide band recording system, the system bandwidth is the frequency in cps at which the output signal is attenuated by approximately 6db. For the narrow band recording system, the system bandwidth represents the maximum frequency for which a reasonable reproduction of the data is possible (8 samples per cycle). Data aliasing will take place in the recording system for any signal greater than four times the bandwidth frequency. Playback techniques can reduce this frequency to as low as one-half of the bandwidth shown. Additional information is indicated by letters:

H High level channel

L Low level channel

NAW Non-multiplexed wide band signal.

CB Narrow band signal originating in control building

Read Out

The read out column indicates the recording system(s) used and the display(s) required.

P Pulse-Amplitude Modulated/Frequency Multiplexed signal recorded on magnetic tape (narrow band)

F Frequency Modulated/Frequency Multiplexed signal recorded on magnetic tape (wide band)

S General Purpose Strip Chart Recorder (Sanborn)

B Control Building Basement Strip Chart Recorder (Sanborn)

E Events Strip Chart Recorder (Sanborn)

C Oscillograph (CEC)

M Control Room Meter

D	Digital Printout and Control Room Meter
*	Strip Chart Alternate
L	Indicating Lamp in Control Room

TABLE 4-1

NRX-A6 MEASUREMENT REQUIREMENTS LIST

MEASUREMENT CHANNEL	DESCRIPTION	LOCATION STA	RAD	THETA	SET-UP RANGE	STD B/W	RD OUT
AA-105T-6.	PROPELLANT FEED LINE	23.4	63.5	120.0	+ - 25 G	1K	FC
AA-107R-6.	PROPELLANT FEED LINE	23.4	82.8	120.0	+ - 25 G	1K	FC
AA-123T-6.	NOZZLE MANIFOLD	105.6	16.0	75.0	+ - 75 G	1K	FC
AA-124R-6.	NOZZLE MANIFOLD	105.5	17.0	75.0	+ - 75 G	1K	FC
AA-125L-6.	NOZZLE MANIFOLD	105.6	16.0	75.0	+ - 75 G	1K	FC
AA-201T-6.	NOZZLE FLANGE	65.5	22.5	165.0	+ - 10 G	1K	FC
AA-202T-6.	PRESSURE VESEL FWD FLG	-14.4	28.0	166.5	+ - 10 G	1K	F
AA-203L-6.	PRESSURE VESEL FWD FLG	-13.4	28.0	166.5	+ - 10 G	1K	F
AA-204R-6.	PRESSURE VESEL FWD FLG	-14.4	29.0	166.5	+ - 10 G	1K	FC
AA-205L-6.	PRESSURE VESEL FWD FLG	-13.4	28.0	340.5	+ - 10 G	1K	F
AA-206T-6.	PRESSURE VESEL FWD FLG	-14.4	28.0	76.5	+ - 10 G	1K	F
AA-207T-6.	NOZZLE FLANGE	65.5	22.5	165.0	+ - 10 G	1K	F
AA-208T-6.	PRESSURE VESEL FWD FLG	-14.4	28.0	166.5	+ - 10 G	1K	F
AA-209L-6.	PRESSURE VESEL FWD FLG	-13.4	28.0	166.5	+ - 10 G	1K	F
AA-210R-6.	PRESSURE VESEL FWD FLG	-14.4	29.0	166.5	+ - 10 G	1K	F
AA-211L-6.	PRESSURE VESEL FWD FLG	-13.4	28.0	340.5	+ - 10 G	1K	F
AA-212T-6.	PRESSURE VESEL FWD FLG	-14.4	28.0	76.5	+ - 10 G	1K	F
AA-701R-6.	CORE SUPPORT PLATE	-4.6	20.5	51.9	+ - 10 G	1K	F
AA-702R-6.	CORE SUPPORT PLATE	-4.8	20.5	141.9	+ - 10 G	1K	F
AA-703L-6.	CORE SUPPORT PLATE	-8.3	6.2	34[illegible]	+ - 10 G	1K	FC
AD-301.-6.	CORE RADIAL DISPLCMENT	50.5	18.9	7.5	+-300MIL	5 L	P
AD-302.-6.	CORE RADIAL DISPLCMENT	50.5	18.9	67.5	+-300MIL	5 L	P
AD-303.-6.	CORE RADIAL DISPLCMENT	50.5	18.9	127.5	+-300MIL	5 L	P
AD-304.-6.	CORE RADIAL DISPLCMENT	50.5	18.9	187.5	+-300MIL	5 L	P
AD-305.-6.	CORE RADIAL DISPLCMENT	50.5	18.9	247.5	+-300MIL	5 L	P
AD-306.-6.	CORE RADIAL DISPLCMENT	50.5	18.9	307.5	+-300MIL	5 L	P
AD-701.-6.	CORE SUPORT PLATE/CORE	0.0	1.2	151.5	+-150MIL	5 L	P
AD-702.-6.	CORE SUPORT PLATE/CORE	0.0	8.5	66.0	+-150MIL	5 L	P
AD-703.-6.	CORE SUPORT PLATE/CORE	0.0	15.0	62.5	+-150MIL	5 L	P
AD-901J-6.	AC-COUPLED AD-701.-6.	NA	NA	NA	+- 25MIL	400	FC
AD-902J-6.	AC-COUPLED AD-702.-6.	NA	NA	NA	+- 50MIL	400	F
AD-903J-6.	AC-COUPLED AD-703.-6.	NA	NA	NA	+- 75MIL	400	F
AD-931J-6.	AC-COUPLED AD-301.-6.	NA	NA	NA	+-30 MIL	500	FC
AD-932J-6.	AC-COUPLED AD-302.-6.	NA	NA	NA	+-30 MIL	500	F
AD-933J-6.	AC-COUPLED AD-303.-6.	NA	NA	NA	+-60 MIL	500	F
AD-934J-6.	AC-COUPLED AD-304.-6.	NA	NA	NA	+-60 MIL	500	FC
AD-935J-6.	AC-COUPLED AD-305.-6.	NA	NA	NA	+-150MIL	500	F
AD-936J-6.	AC-COUPLED AD-306.-6.	NA	NA	NA	+-150MIL	500	F
AP-102.-6A	NOZZLE MANIFOLD INLET	107.8	24.0	120.0	0-1200PS	5 H	PS
AP-104.-6A	NOZZLE MANIFOLD INLET	TEED	TO	P-102	0-1200PS	5 H	PS
AP-106.-6A	NOZZLE MANIFOLD INLET	TEED	TO	P-102	0-1200PS	5 H	P*
AP-108.-6A	NOZZLE MANIFOLD INLET	TEED	TO	P-102	0-1200PS	5 H	P*
AP-133D-6.	NOZZ MANIFOLD INLET TO	TEED	TO	P-102	0-200PSD	5 H	PS
AP-133L-6.	REFLEC INLET PRES DROP	TEED	TO	P-302	LOW 226		
AP-150.-6.	NOZZLE CHAMBER	70.0	13.0	30.0	0-750PSA	400	FC
AP-152.-6A	NOZZLE CHAMBER	70.0	13.0	210.0	0-750PSA	5 H	PS
AP-154.-6A	NOZZLE CHAMBER	TEED	TO	P-152	0-750PSA	5 H	P*
AP-156.-6A	NOZZLE CHAMBER	TEED	TO	P-152	0-750PSA	5 H	P*
AP-160.-6.	NOZZLE CHAMBER SIMULAT	70.0	13.0	0.0	0-750PSA	5 L	P
AP-162.-6.	NOZZLE CHAMBER SIMULAT	70.0	13.0	60.0	0-750PSA	5 L	P
AP-164.-6.	NOZZLE CHAMBER SIMULAT	70.0	13.0	120.0	0-750PSA	5 L	P
AP-166.-6.	NOZZLE CHAMBER SIMULAT	70.0	13.0	300.0	0-750PSA	5 L	P
AP-168.-6.	REF P160 THRU 166 PRES	IN	FLOW	C-RM	0-750PSA	5 L	P
AP-300.-6.	REFLEC INLET PLENUM	52.5	20.2	353.7	0-880PSA	5 H	PS

TABLE 4-1 (Continued)

MEASUREMENT CHANNEL	DESCRIPTION	LOCATION STA	RAD	THETA	SET-UP RANGE	SYS B/W	RO OUT
AP-301D-6.	REFLEC AXIAL PRES DROP	TEED	TO	P-303	0-75PSID	5 H	PSM
AP-301L-6.		TEED	TO	P-304	LOW LEG		
AP-302.-6.	REFLEC INLET PLENUM	52.5	20.2	293.7	0-680PSA	5 H	P*
AP-303D-6.	REFLEC AXIAL PRES DROP	TEED	TO	P-302	0-75PSID	5 H	P
AP-303L-6.		TEED	TO	P-304	LOW LEG		
AP-304.-6.	REFLEC OUTLET PLENUM	-0.4	20.2	290.7	0-500PSA	5 H	P
AP-311D-6.	SUPPORT CONE PRES DROP	TEED	TO	P-300	0-50PSID	5 L	P
AP-311L-6.		52.9	24.6	292.3	LOW LEG		
AP-413D-6.	SEAL CHAMBER 5 TO 10	15.0	18.9	280.0	0-50PSID	5 L	P
AP-413L-6.	PRESSURE DROP	TEED	TO	P-414	LOW LEG		
AP-414.-6.	SEAL CHAMBER 10	21.3	18.9	280.0	0-800PSA	5 H	PS
AP-415D-6.	SEAL CHAMBER 8 TO 10	16.1	18.9	283.0	0-25PSID	5 H	PS
AP-415L-6.	PRESSURE DROP	TEED	TO	P-414	LOW LEG		
AP-416.-6.	SEAL CHAMBER 18	30.5	18.9	280.0	0-600PSA	5 H	PS
AP-417D-6.	SEAL CHAMBER 9 TO 10	19.1	18.9	280.0	0-25PSID	5 L	P
AP-417L-6.	PRESSURE DROP	TEED	TO	P-414	LOW LEG		
AP-419D-6.	SEAL CHAMBER 10 TO 11	TEED	TO	P-414	0-25PSID	5 L	P
AP-419L-6.	PRESSURE DROP	23.3	18.9	280.0	LOW LEG		
AP-421D-6.	SEAL CHAMBER 10 TO 12	TEED	TO	P-414	0-25PSID	5 H	PS
AP-421L-6.	PRESSURE DROP	25.4	18.9	280.0	LOW LEG		
AP-423D-6.	SEAL CHAMBER 14 TO 18	29.5	18.9	280.0	0-25PSID	5 L	P
AP-423L-6.	PRESSURE DROP	TEED	TO	P-416	LOW LEG		
AP-425D-6.	SEAL CHAMBER 16 TO 18	33.6	18.9	280.0	0-25PSID	5 L	
AP-425L-6.	PRESSURE DROP	TEED	TO	P-416	LOW LEG		
AP-427D-6.	SEAL CHAMBER 18 TO 20	TEED	TO	P-416	0-25PSID	5 L	P
AP-427L-6.	PRESSURE DROP	42.6	18.9	280.0	LOW LEG		
AP-429D-6.	SEAL CHAMBER 18 TO 21	TEED	TO	P-416	0-25PSID	5 L	P
AP-429L-6.	PRESSURE DROP	44.7	18.9	280.0	LOW LEG		
AP-431D-6.	SEAL CHAMBER 18 TO 22	TEED	TO	P-416	0-25PSID	5 H	PS
AP-431L-6.	PRESSURE DROP	46.7	18.9	280.0	LOW LEG		
AP-433D-6.	CORE INLET PLENUM TO	TEED	TO	P-604	0-50PSID	5 L	P
AP-433L-6.	SEAL CHAMBER 10	TEED	TO	P-414	LOW LEG		
AP-435D-6.	SEAL CHAMBER 10 TO 18	TEED	TO	P-414	0-100PSID	5 L	P
AP-435L-6.	PRESSURE DROP	TEED	TO	P-416	LOW LEG		
AP-437D-6.	SEAL CHAMBER 18 TO	TEED	TO	P-416	0-100PSD	5 H	P
AP-437L-6.	CORE EXIT PRESS DROP	TEED	TO	P-702	LOW LEG		
AP-501D-6.	REFLEC OUTLET TO CORE	TEED	TO	P-304	0-30PSID	5 L	P
AP-501L-6.	INLET PLENUM PRES DROP	TEED	TO	P-604	LOW LEG		
AP-502.-6.	ABS P EVALUATION XDCR	-28.5	6.0	56.0	0-800PSA	400	F
AP-503D-6.	DELTA P EVALUTION XDCR	-28.5	8.0	45.0	+-50PSID	5 L	P
AP-504.-6.	ABS P EVALUATION XDCR	-28.5	7.0	47.0	0-800PSA	5 L	P
AP-602.-6.	CORE INLET PLENUM	-0.8	11.8	253.0	0-800PSA	5 H	P
AP-603D-6.	CORE AXIAL PRESS DROP	TEED	TO	P-604	0-165PSD	5 H	PS
AP-603L-6.		TEED	TO	P-702	LOW LEG		
AP-604.-6.	CORE INLET PLENUM	-0.8	12.7	312.0	0-600PSA	5 H	PS
AP-605D-6.	CORE AXIAL PRESS DROP	TEED	TO	P-604	0-165PSD	5 H	PS
AP-605L-6.		TEED	TO	P-704	LOW LEG		
AP-701D-6.	REACTOR PRESSURE DROP	TEED	TO	P-302	0-200PSD	5 H	PS
AP-701L-6.		TEED	TO	P-702	LOW LEG		
AP-702.-6.	CORE EXIT	50.8	18.9	280.0	0-800PSA	300	F
AP-703D-6.	REACTOR PRESSURE DROP	TEED	TO	P-302	0-200PSD	5 H	PS
AP-703L-6.		TEED	TO	P-704	LOW LEG		
AP-704.-6.	CORE EXIT	50.8	18.9	340.0	0-800PSA	5 H	PS
AP-705.-6.	CORE EXIT INTERNL XDCR	50.8	18.9	160.0	0-300PSA	300	F
AP-772.-6.	ABS P EVALUATION XDCR	-8.3	14.7	287.0	0-800PSA	5 L	P

TABLE 4-1 (Continued)

MEASUREMEN CHANNEL	DESCRIPTION	LOCATION STA	RAD	THETA	SET-UP RANGE	SYS B/W	RD OUT
AS-229H-6.	PRESSURE VESSEL	45.0	25.7	168.5	±3.5KUI	5 L	P
AS-231H-6.	PRESSURE VESSEL	31.0	25.7	168.5	±3.5KUI	5 L	P
AS-233H-6.	PRESSURE VESSEL	31.0	25.7	258.5	±3.5KUI	5 L	P
AS-242L-6.	PRESSURE VESSEL	-11.3	25.7	171.5	±3.5KUI	5 L	P
AS-243H-6.	PRESSURE VESSEL	-11.3	25.7	171.5	±3.5KUI	5 L	P
AS-244L-6.	PRESSURE VESSEL	-12.6	25.7	171.5	±3.5KUI	5 L	P
AS-301.-6.	REFLECTOR BOLTS	56.4	21.0	45.0	0-75KPSI	5 L	P
AS-302.-6.	REFLECTOR BOLTS	56.4	21.0	165.0	0-75KPSI	5 L	P
AS-303.-6.	REFLECTOR BOLTS	56.4	21.0	225.0	0-75KPSI	5 L	P
AS-304.-6.	REFLECTOR BOLTS	56.4	21.0	345.0	0-75KPSI	5 L	P
AS-701.-6.	TIE ROD	-3.2	0.1	0.0	±75KPSI	5 L	P
AS-702.-6.	TIE ROD	-3.2	0.1	0.0	±75KPSI	5 L	P
AS-703.-6.	TIE ROD	-3.2	3.5	30.0	±75KPSI	5 L	P
AS-704.-6.	TIE ROD	-3.2	3.5	30.0	±75KPSI	5 L	P
AS-705.-6.	TIE ROD	-3.2	7.2	45.8	±75KPSI	5 L	P
AS-706.-6.	TIE ROD	-3.2	7.2	45.8	±75KPSI	5 L	P
AS-707.-6.	TIE ROD	-3.2	11.1	50.9	±75KPSI	5 L	P
AS-708.-6.	TIE ROD	-3.2	11.1	50.9	±75KPSI	5 L	P
AS-709.-6.	TIE ROD	-3.2	16.3	54.7	±75KPSI	5 L	P
AS-710.-6.	TIE ROD	-3.2	16.3	54.7	±75KPSI	5 L	P
AS-901J-6.	AC-COUPLED AS-701.-6.	NA	NA	NA	±9K PSI	750	F
AS-902J-6.	AC-COUPLED AS-702.-6.	NA	NA	NA	±45KPSI	750	F
AS-903J-6.	AC-COUPLED AS-703.-6.	NA	NA	NA	±9K PSI	750	FC
AS-904J-6.	AC-COUPLED AS-704.-6.	NA	NA	NA	±9K PSI	750	F
AS-905J-6.	AC-COUPLED AS-705.-6.	NA	NA	NA	±9K PSI	750	F
AS-906J-6.	AC-COUPLED AS-706.-6.	NA	NA	NA	±9K PSI	750	F
AS-907J-6.	AC-COUPLED AS-707.-6.	NA	NA	NA	±18KPSI	750	FC
AS-908J-6.	AC-COUPLED AS-708.-6.	NA	NA	NA	±45KPSI	750	F
AS-909J-6.	AC-COUPLED AS-709.-6.	NA	NA	NA	±18KPSI	750	F
AS-910J-6.	AC-COUPLED AS-710.-6.	NA	NA	NA	±4.5KPS	750	F
AS-911J-6.	AC-COUPLED AS-301.-6.	NA	NA	NA	±10KPSI	500	F
AS-912J-6.	AC-COUPLED AS-302.-6.	NA	NA	NA	±20KPSI	500	F
AS-913J-6.	AC-COUPLED AS-303.-6.	NA	NA	NA	±30KPSI	500	F
AS-914J-6.	AC-COUPLED AS-304.-6.	NA	NA	NA	±40KPSI	500	F
AT-100.-6.	PROPELLANT FEED LINE	26.6	80.0	120.0	30 - 60R	5 L	P
AT-101.-6.	NOZZLE MANIFOLD INLET	110.0	24.0	120.0	30-540 R	5 H	PS
AT-102.-6.	PROPELLANT FEED LINE	23.4	80.0	120.0	30-60 R	5 L	P
AT-103.-6.	PROPELLANT FEED LINE	110.0	24.0	120.0	30-540 R	5 L	P
AT-104.-6.	MOUNT. ACCELRMTR BLOCK	23.4	82.8	120.0	35-655 R	5 L	P
AT-105.-6.	MOUNT. ACCELRMTR BLOCK	105.5	16.0	75.0	35-655 R	5 L	P
AT-120.-6.	NOZZLE MANIFOLD	107.5	15.9	30.0	30-60 R	5 H	P
AT-121.-6.	NOZZLE MANIFOLD	107.5	15.9	210.0	30-60 R	5 H	P
AT-123.-6.	NOZZLE MANIFOLD	107.5	15.9	300.0	30-540 R	5 H	P
AT-133.-6.	NOZZLE EXTERNAL WALL	72.5	11.2	168.5	35-655 R	5 L	P
AT-134.-6.	NOZZLE EXTERNAL WALL	69.6	15.1	168.5	35-655 R	5 L	P
AT-135.-6.	NOZZLE EXTERNAL WALL	66.7	18.2	168.5	35-655 R	5 L	P
AT-136.-6.	NOZZLE PASS THRU BOSS	71.5	13.7	30.0	35-1K R	5 L	P
AT-137.-6.	NOZZLE PASS THRU BOSS	71.5	13.7	210.0	35-1K R	5 L	P
AT-138.-6A	NOZZLE CHAMBER	68.8	11.8	90.0	492-4785	5 H	P*
AT-139.-6A	NOZZLE CHAMBER	68.8	11.8	150.0	492-4785	5 H	PS
AT-140.-6A	NOZZLE CHAMBER	68.8	11.8	270.0	492-4785	5 H	P*
AT-141.-6A	NOZZLE CHAMBER	68.5	11.5	330.0	492-4785	5 H	PS
AT-143.-6.	NOZZLE BOLT	65.4	21.0	22.5	35-655 R	5 L	P
AT-145.-6.	NOZZLE BOLT	65.4	21.0	142.5	35-655 R	5 L	P

TABLE 4-1 (Continued)

MEASUREMENT CHANNEL	DESCRIPTION	LOCATION STA	RAD	THETA	SET-UP RANGE	SYS	B/W	RD OUT
AT-150.-6.	NOZZLE FLANGE	65.0	21.0	24.4	35-655 R	5	L	P
AT-151.-6.	NOZZLE FLANGE	65.0	21.0	144.4	35-655 R	5	L	P
AT-152.-6.	MOUNT, ACCELRMTR BLOCK	65.0	22.0	165.0	35-655 R	5	L	P
AT-160.-6.	SURFACE OF AP-160.-6.	70.0	13.0	0.0	160-1K R	5	L	P
AT-161.-6.	SURFACE, AP-160 BOSS	70.0	13.0	0.0	160-1K R	5	L	P
AT-162.-6.	SURFACE OF AP-162.-6.	70.0	13.0	60.0	160-1K R	5	L	P
AT-163.-6.	SURFACE, AP-162 BOSS	70.0	13.0	60.0	160-1K R	5	L	P
AT-164.-6.	SURFACE OF AP-164.-6.	70.0	13.0	120.0	160-1K R	5	L	P
AT-165.-6.	SURFACE, AP-164 BOSS	70.0	13.0	120.0	160-1K R	5	L	P
AT-166.-6.	SURFACE OF AP-166.-6.	70.0	13.0	300.0	160-1K R	5	L	P
AT-167.-6.	SURFACE, AP-166 BOSS	70.0	13.0	300.0	160-1K R	5	L	P
AT-222.-6.	PRESSURE VESSEL FWD	31.0	25.7	168.5	35-655 R	5	H	PS
AT-223.-6.	PRESSURE VESSEL FWD	31.0	25.7	258.5	35-655 R	5	L	P
AT-230.-6.	PRESSURE VESSEL FWD	45.0	25.7	168.5	35-655 R	5	L	P
AT-231.-6.	PRESSURE VESSEL AFT	-12.0	25.7	168.5	35-655 R	5	L	P
AT-232.-6.	MOUNT, ACCELRMTR BLOCK	-13.0	28.0	165.0	35-655 R	5	L	P
AT-233.-6.	P.V. FLANGE PERIPHERY	-17.5	27.3	144.0	35-655 R	5	L	P
AT-234.-6.	P.V. FLANGE PERIPHERY	-17.5	27.3	264.0	35-655 R	5	L	P
AT-235.-6.	P.V. FLANGE PERIPHERY	-17.5	27.3	24.0	35-655 R	5	L	P
AT-245.-6.	P.V. BOLT FWD FLG	-18.8	26.1	24.0	35-655 R	5	L	P
AT-246.-6.	P.V. BOLT FWD FLG	-18.8	26.1	144.0	35-655 R	5	L	P
AT-247.-6.	P.V. BOLT FWD FLG	-18.8	26.1	264.0	35-655 R	5	L	P
AT-249.-6.	PRES VES FLAME SPRAY	43.0	25.7	22.5	35- 1K R	5	L	P
AT-250.-6.	PRES VES FLAME SPRAY	43.0	25.7	28.5	35-655 R	5	L	P
AT-251.-6.	PRES VES FLAME SPRAY	43.0	25.7	31.5	35-655 R	5	L	P
AT-252.-6.	PRES VES FLAME SPRAY	43.0	25.7	34.5	35- 1K R	5	L	P
AT-253.-6.	PRES VES FLAME SPRAY	43.0	25.7	19.5	35-655 R	5	L	P
AT-254.-6.	PRES VES FLAME SPRAY	43.0	25.8	25.5	35-655 R	5	L	P
AT-255.-6.	PRES VES FLAME SPRAY	43.0	25.8	34.5	200-1K R	5	L	P
AT-256.-6.	PRES VES FLAME SPRAY	43.0	25.7	40.5	200-1K R	5	L	P
AT-257.-6.	PRES VES FLAME SPRAY					5	L	P
AT-258.-6.	PRES VES FLAME SPRAY					5	L	P
AT-260.-6.	PRESSURE VESEL CLOSURE	-22.8	7.2	172.5	35-655 R	5	L	P
AT-261.-6.	PRESSURE VESEL CLOSURE	-22.8	7.2	352.0	35-655 R	5	L	P
AT-301.-6.	REFLECTOR CYLINDER	21.0	22.7	199.5	35-1003R	5	H	PS
AT-302.-6.	REFLECTOR CYLINDER	21.3	20.9	199.5	35-1003R	5	H	PS
AT-303.-6.	REFLECTOR CYLINDER	21.1	19.1	193.0	35-1003R	5	H	PS
AT-304.-6.	REFLECTOR CYLINDER	21.4	19.8	180.0	35-1003R	5	L	P
AT-305.-6.	REFLECTOR CYLINDER	21.2	19.9	202.5	35-1003R	5	L	P
AT-307.-6.	REFLECTOR CYLINDER	21.4	19.8	90.0	35-1003R	5	L	P
AT-308.-6.	REFLECTOR CYLINDER	21.1	19.1	76.7	35-1003R	5	H	P
AT-309.-6.	REFLECTOR CYLINDER	21.2	19.9	82.5	35-1003R	5	L	P
AT-311.-6.	REFLECTOR CYLINDER	21.3	20.9	78.8	35-1003R	5	L	P
AT-312.-6.	REFLECTOR CYLINDER	21.0	22.7	78.8	35-1003R	5	H	P
AT-313.-6.	REFLECTOR CYLINDER	50.5	19.1	46.7	35-1003R	5	L	P
AT-314.-6.	REFLECTOR CYLINDER	50.5	19.1	166.7	35-1003R	5	H	P
AT-315.-6.	REFLECTOR CYLINDER	50.5	22.7	229.5	35-1003R	5	H	P
AT-316.-6.	REFLECTOR CYLINDER	50.5	19.8	240.0	35-1003R	5	L	P
AT-317.-6.	REFLECTOR CYLINDER	50.5	19.1	226.7	35-1003R	5	H	P
AT-318.-6.	REFLECTOR CYLINDER	50.5	20.5	229.5	35-1003R	5	L	P
AT-320.-6.	REFLECTOR CYLINDER	50.5	19.8	233.2	35-1003R	5	L	P
AT-321.-6.	REFLECTOR CYLINDER	50.5	19.1	286.7	35-1003R	5	L	P
AT-322.-6.	REFLECTOR CYLINDER	17.2	24.5	181.8	35-1003R	5	L	P
AT-323.-6.	REFLECTOR CYLINDER	17.2	24.5	83.8	35-1003R	5	L	P

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TABLE 4-1 (Continued)

MEASUREMENT CHANNEL	DESCRIPTION	LOCATION STA	LOCATION RAD	LOCATION THETA	SET-UP RANGE	SYS B/W		RO OUT
AT-324.-6.	REFLECTOR CYLINDER	51.1	24.6	240.0	35-1003R	5	L	P
AT-331.-6.	REFLECTOR BOLT	25.7	21.1	15.0	35-1003R	5	L	P
AT-332.-6.	REFLECTOR BOLT	25.7	21.1	135.0	35-1003R	5	L	P
AT-333.-6.	REFLECTOR BOLT	25.7	21.1	195.0	35-1003R	5	L	P
AT-334.-6.	REFLECTOR BOLT	25.7	21.1	315.0	35-1003R	5	L	P
AT-342.-6.	DRUM VANE EXIT GAS	-0.9	22.3	115.0	35-653.5	5	L	P
AT-343.-6.	DRUM ANNULUS EXIT GAS	-0.9	22.3	125.0	35-653.5	5	L	P
AT-344.-6.	REF CYLINDER EXIT GAS	0.0	19.3	7.5	35-653.5	5	H	P
AT-345.-6.	REF CYLINDER EXIT GAS	0.0	19.3	12.5	35-653.5	5	H	P
AT-346.-6.	REF CYLINDER EXIT GAS	-0.1	23.3	9.0	35-653.5	5	H	P
AT-360.-6.	CONTROL DRUM NO 5	8.0	22.4	120.0	35-1003R	5	H	PS
AT-361.-6.	CONTROL DRUM NO 5	8.0	22.4	120.0	35-1003R	5	L	P
AT-362.-6.	CONTROL DRUM NO 5	32.0	22.4	120.0	35-1003R	5	H	PS
AT-363.-6.	CONTROL DRUM NO 5	32.0	22.4	120.0	35-1003R	5	L	P
AT-364.-6.	IN AD-301.-6.	NA	NA	NA	35-1003R	5	L	P
AT-365.-6.	IN AD-302.-6.	NA	NA	NA	35-1003R	5	L	P
AT-366.-6.	IN AD-303.-6.	NA	NA	NA	35-1003R	5	L	P
AT-367.-6.	IN AD-304.-6.	NA	NA	NA	35-1003R	5	L	P
AT-368.-6.	IN AD-305.-6.	NA	NA	NA	35-1003R	5	L	P
AT-369.-6.	IN AD-306.-6.	NA	NA	NA	35-1003R	5	L	P
AT-370.-6.	REFLECTOR INLET PLENUM	53.3	21.7	46.0	30-540 R	5	H	PS
AT-371.-6.	REFLECTOR INLET PLENUM	53.3	21.7	106.0	30-540 R	5	H	P*
AT-372.-6.	REFLECTOR INLET PLENUM	53.3	21.7	166.0	30-540 R	5	H	PS
AT-373.-6.	REFLECTOR INLET PLENUM	53.3	21.7	226.0	30-540 R	5	H	P*
AT-374.-6.	REFLECTOR INLET PLENUM	53.3	21.7	286.0	30-540 R	5	H	P
AT-375.-6.	REFLECTOR INLET PLENUM	53.3	21.7	346.0	30-540 R	5	H	P
AT-381.-6.	REFLECTOR/P.V. ANNULUS	53.2	24.7	292.7	35-655 R	5	L	P
AT-421.-6.	SEAL CHAMBER 10 GAS	21.2	16.2	169.8	137-1968	5	L	P
AT-422.-6.	SEAL CHAMBER 11 GAS	23.2	16.2	189.8	137-1968	5	L	P
AT-423.-6.	SEAL CHAMBER 12 GAS	25.3	16.2	169.6	137-1968	5	H	PS
AT-424.-6.	SEAL CHAMBER 14 GAS	29.4	16.2	189.8	137-1968	5	H	P
AT-425.-6.	SEAL CHAMBER EXIT GAS	51.1	16.2	40.0	137-1968	5	H	PS
AT-426.-6.	SEAL CHAMBER EXIT GAS	51.1	16.2	100.0	137-1968	5	H	PS
AT-427.-6.	SEAL CHAMBER EXIT GAS	51.1	16.2	160.0	492-4785	5	H	P
AT-428.-6.	SEAL CHAMBER EXIT GAS	51.1	16.2	220.0	137-1968	5	H	P
AT-429.-6.	SEAL CHAMBER EXIT GAS	51.1	16.2	280.0	137-1968	5	H	P
AT-430.-6.	SEAL CHAMBER EXIT GAS	51.1	16.2	340.0	492-4785	5	H	P
AT-501.-6.	SHIELD DOME END GAS	-23.3	18.5	36.0	35-653.5	5	H	PS
AT-502.-6.	SHIELD DOME END GAS	-23.3	18.5	96.0	35-653.5	5	L	P
AT-503.-6.	SHIELD DOME END GAS	-23.3	18.5	156.0	35-653.5	5	H	PS
AT-504.-6.	SHIELD DOME END GAS	-23.3	18.5	216.0	35-653.5	5	L	P
AT-505.-6.	SHIELD DOME END GAS	-23.3	16.5	276.0	35-653.5	5	H	PS
AT-506.-6.	SHIELD DOME END GAS	-23.3	18.5	336.0	35-653.5	5	L	P
AT-507.-6.	IN AP-502.-6., COIL A	NA	NA	NA	35-655 R	5	L	P
AT-508.-6.	IN AP-502.-6., COIL B	NA	NA	NA	35-655 R	5	L	P
AT-601.-6A	CORE ELEMENT	1.0	2.1	12.0	137-1968	5	H	PS
AT-602.-6A	CORE ELEMENT	1.0	16.5	299.0	137-1968	5	H	P
AT-603.-6A	CORE ELEMENT	1.0	17.0	319.0	137-1968	5	H	P
AT-604.-6A	CORE ELEMENT	1.0	5.1	303.0	137-1968	5	H	P*
AT-611.-6.	CORE ELEMENT	26.0	2.3	1.5	492-4785	5	L	P
AT-612.-6.	CORE ELEMENT	26.0	2.4	121.5	492-4785	5	H	P
AT-613.-6.	CORE ELEMENT	26.0	1.8	126.0	492-4785	5	L	P
AT-614.-6.	CORE ELEMENT	26.0	16.1	121.5	492-4785	5	L	P
AT-615.-6A	CORE ELEMENT	26.0	16.1	122.0	492-4785	5	H	P

[redacted]

TABLE 4-1 (Continued)

MEASUREMENT CHANNEL	DESCRIPTION	LOCATION STA	RAD	THETA	SET-UP RANGE	SYS B/M	RO OUT
AT-616.-6A	CORE ELEMENT	26.0	16.8	140.5	492-4785	5 H	P
AT-617.-6*	CORE ELEMENT	26.0	14.4	120.5	492-4785	5 H	P
AT-618.-6A	CORE ELEMENT	26.0	13.8	121.5	492-4785	5 H	P
AT-619.-6A	CORE ELEMENT	26.0	14.0	135.0	492-4785	5 H	P
AT-620.-6.	CORE ELEMENT	26.0	16.3	133.0	492-4785	5 L	P
AT-621.-6A	CORE ELEMENT	26.0	14.0	301.0	492-4785	5 H	P
AT-622.-6.	CORE ELEMENT	26.0	2.1	188.0	492-4785	5 L	P
AT-623.-6.	CORE ELEMENT	26.0	16.3	300.5	492-4785	5 H	P
AT-624.-6.	CORE ELEMENT	26.0	15.7	301.0	492-4785	5 H	P
AT-625.-6A	CORE ELEMENT	26.0	16.3	300.5	492-4785	5 H	P
AT-626.-6*	CORE ELEMENT	26.0	9.8	301.5	492-4785	5 H	P
AT-627.-6*	CORE ELEMENT	26.0	14.6	315.0	492-4785	5 H	P
AT-628.-6.	CORE ELEMENT	26.0	2.1	308.0	492-4785	5 L	P
AT-629.-6A	CORE ELEMENT	26.0	12.7	45.0	492-4785	5 H	PS
AT-630.-6A	CORE ELEMENT	26.0	12.4	154.0	492-4785	5 H	P
AT-631.-6A	CORE ELEMENT	26.0	12.4	274.0	492-4785	5 H	P
AT-632.-6A	CORE ELEMENT	26.0	12.8	16.0	492-4785	5 H	P*
AT-633.-6A	CORE ELEMENT	26.0	12.7	343.0	492-4785	5 H	P
AT-634.-6A	CORE ELEMENT	26.0	12.8	76.0	492-4785	5 H	P
AT-638.-6A	CORE ELEMENT	26.0	12.6	196.0	492-4785	5 H	P*
AT-639.-6A	CORE ELEMENT	26.0	12.8	223.0	492-4785	5 H	PS
AT-640.-6A	CORE ELEMENT	26.0	12.8	316.0	492-4785	5 H	P
AT-641.-6A	CORE ELEMENT	26.0	16.8	320.5	492-4785	5 H	P
AT-642.-6.	CORE ELEMENT	26.0	16.5	313.5	492-4785	5 L	P
AT-688.-6.	CLUSTER EXIT GAS	54.75	15.1	135.5	492-4785	5 L	P
AT-689.-6A	CLUSTER EXIT GAS	54.75	11.3	140.5	492-4785	5 H	P
AT-690.-6*	CLUSTER EXIT GAS	54.75	10.5	123.0	492-4785	5 H	P
AT-691.-6.	CLUSTER EXIT GAS	54.75	2.6	191.0	492-4785	5 L	P
AT-692.-6.	CLUSTER EXIT GAS	54.75	2.0	311.0	492-4785	5 L	P
AT-693.-6*	CLUSTER EXIT GAS	54.75	14.5	302.0	492-4785	5 H	P
AT-694.-6A	CLUSTER EXIT GAS	54.75	11.2	320.5	492-4785	5 H	P
AT-695.-6.	CLUSTER EXIT GAS	54.75	15.1	315.5	492-4785	5 L	P
AT-696.-6.	CLUSTER EXIT GAS	54.75	4.6	6.5	492-4785	5 H	P
AT-697.-6.	CLUSTER EXIT GAS	54.75	6.6	4.5	492-4785	5 H	P
AT-698.-6.	CLUSTER EXIT GAS	54.75	8.6	3.5	492-4785	5 H	P
AT-699.-6A	CLUSTER EXIT GAS	54.75	10.6	3.0	492-4785	5 H	P
AT-700.-6A	CLUSTER EXIT GAS	54.75	12.6	2.5	492-4785	5 H	P
AT-701.-6A	CLUSTER EXIT GAS	54.75	14.6	2.0	492-4785	5 H	P
AT-702.-6.	CLUSTER EXIT GAS	54.75	15.8	353.0	492-4785	5 L	P
AT-703.-6.	CLUSTER EXIT GAS	54.75	16.6	2.0	492-4785	5 H	P
AT-704.-6.	CLUSTER EXIT GAS	54.75	16.8	350.0	492-4785	5 L	P
AT-705.-6.	CLUSTER EXIT GAS	54.75	17.0	223.0	492-4785	5 L	P
AT-706.-6.	CLUSTER EXIT GAS	54.75	16.5	182.0	492-4785	5 L	P
AT-707.-6A	CLUSTER EXIT GAS	54.75	13.2	224.0	492-4785	5 H	P
AT-708.-6.	CLUSTER EXIT GAS	54.75	14.7	83.0	492-4785	5 L	P
AT-711.-6.	TIE ROD MATERIAL	54.0	16.3	132.0	137-1968	5 H	PS
AT-712.-6.	TIE ROD MATERIAL	54.0	16.3	312.0	137-1968	5 L	P
AT-713.-6A	TIE ROD MATERIAL	54.0	2.0	120.0	137-1968	5 H	PS
AT-714.-6A	TIE ROD MATERIAL	54.0	16.0	300.0	137-1968	5 H	PS
AT-715.-6A	TIE ROD MATERIAL	54.0	14.0	120.0	137-1968	5 H	PS
AT-716.-6.	TIE ROD MATERIAL	54.0	16.3	295.0	137-1968	5 L	P
AT-717.-6A	TIE ROD MATERIAL	54.	15.9	120.0	137-1968	5 H	P
AT-718.-6A	TIE ROD MATERIAL	54.0	8.0	300.0	137-1968	5 H	PS
AT-719.-6*	TIE ROD MATERIAL	54.0	6.0	120.0	137-1968	5 H	P[illegible]

TABLE 4-1 (Continued)

MEASUREMENT CHANNEL	DESCRIPTION	LOCATION STA	LOCATION RAD	LOCATION THETA	SET-UP RANGE	SYS B/W	RC OUT
AT-720.-6.	TIE ROD MATERIAL	54.0	4.0	300.0	137-1968	5 H	PS
AT-771.-6.	IN AP-772.-6., COIL A	NA	NA	NA	35-655 R	5 L	P
AT-772.-6.	IN AP-772.-6., COIL B	NA	NA	NA	35-655 R	5 L	P
AT-773.-6.	CORE SUPPORT PLATE	-1.4	10.5	170.0	35-1063R	5 H	PS
AT-774.-6.	CORE SUPPORT PLATE	-1.4	1.0	61.0	35-1063R	5 H	PS
AT-776.-6.	CORE INLET PLENUM	-0.8	1.0	0.0	35-653.5	5 H	P
AT-777.-6.	CORE INLET PLENUM	-0.8	9.0	318.0	35-653.5	5 H	P
AT-778.-6.	CORE INLET PLENUM	-0.8	9.0	73.0	35-653.5	5 L	P
AT-779.-6.	CORE INLET PLENUM	-0.8	9.0	198.0	35-653.5	5 H	P
AT-780.-6.	CORE INLET PLENUM	-0.8	13.4	195.0	35-653.5	5 L	P
AT-781.-6.	CORE INLET PLENUM	-0.8	13.4	130.0	35-653.5	5 L	P
AT-782.-6.	CORE INLET PLENUM	-0.8	13.4	75.5	35-653.5	5 H	P
AT-783.-6.	CORE INLET PLENUM	-0.8	13.4	15.0	35-653.5	5 L	P
AT-784.-6.	CORE INLET PLENUM	-0.8	13.4	315.0	35-653.5	5 L	P
AT-785.-6.	CORE INLET PLENUM	-0.8	13.4	255.0	35-653.5	5 H	P
AT-786.-6.	CORE INLET PLENUM	-0.8	16.8	315.0	35-653.5	5 L	P
AT-787.-6.	CORE INLET PLENUM	-0.8	16.8	75.0	35-653.5	5 L	P
AT-788.-6.	CORE INLET PLENUM	-0.8	16.8	195.[illegible]	[illegible]	5 H	P
AT-830.-6.	CAR DECK SS CALOR SLUG	-106	108	120.0	[illegible]	5 L	P
AT-831.-6.	CAR DECK SS CAL SHELL	-106	108	120.0	492-1250	5 L	P
AT-832.-6.	CAR DECK SS CALOR CASE	-106	108	120.0	492-1250	5 L	P
AT-834.-6.	CAR DECK AL CALOR SLUG	-106	108	120.0	500-1K R	5 L	P
AT-835.-6.	CAR DECK AL CAL SHELL	-106	108	120.0	492-1250	5 L	P
AT-836.-6.	CAR DECK AL CALOR CASE	-106	108	120.0	492-1250	5 L	P
AT-838.-6.	TCC WALL AL CALOR SLUG	26	156	120.0	500-1K R	5 L	P
AT-839.-6.	TCC WALL AL CAL SHELL	26	156	120.0	492-1250	5 L	P
AT-840.-6.	TCC WALL AL CALOR CASE	26	156	120.0	492-1250	5 L	P
AT-876.-6.	LN2 DEWAR REF TEMP 1	DEWAR	IN	PRIVY	35-550 R	5 H	PM
AT-877.-6.	LN2 DEWAR REF TEMP 2	DEWAR	IN	PRIVY	35-550 R	5 H	PM
AT-878.-6.	PACE REF JUNCTION	IN	CAR	PRIVY	450-750R	5 H	PSM
AT-879.-6.	PACE REF JUNCTION	IN	CAR	PRIVY	450-750R	5 H	PSM
AT-880.-6.	PRIVY ROOF TI CAL SLUG	-55	0	0	500-1500	5 L	P
AT-881.-6.	PRIVY ROOF TI CAL SHEL	-55	0	0	492-1365	5 L	P
AT-882.-6.	PRIVY ROOF TI CAL CASE	-55	0	0	492-1365	5 L	P
AT-884.-6.	PRIVY ROOF AL CAL SLUG	-55	0	0	500-1K R	5 L	P
AT-885.-6.	PRIVY ROOF AL CAL SHEL	-55	0	0	492-1250	5 L	P
AT-886.-6.	PRIVY ROOF AL CAL CASE	-55	0	0	492-1500	5 L	P
AT-896.-6.	NOZZLE BE CALOR SLUG	63.0	23.0	113.0	500-1250	5 L	P
AT-897.-6.	NOZZLE BE CALOR SHEL	63.0	23.0	113.0	492-1365	5 L	P
AT-898.-6.	NOZZLE BE CALOR CASE	63.0	23.0	113.0	492-1365	5 L	P
IV-110.-C.	AVG NOZZLE MANIFOLD	INLET	NA	NA	0-1200PS	5CB	PSM
IV-142.-C.	AVG NOZZLE CHAMBER TEM	NA	NA	NA	492-4765	5CB	PSM
IV-158.-C.	AVG NOZZLE CHAMBR PRES	NA	NA	NA	0-750PSA	5CB	PSM
IV-605.-C.	AVG CORE STATION TEMP	26.0	NA	NA	492-4785	5CB	PSM
IV-606.-C.	AVG CORE STATION TEMP	26.0	NA	NA	492-4765	5CB	PSM
IV-607.-C.	AVG CORE STATION TEMP	1.0	NA	NA	137-1968	5CB	PSM
IV-680.-C.	AVG CLUSTER EXIT GAS	NA	NA	NA	492-4765	5CB	PSM
IV-710.-C.	AVG TIE ROD MATERIAL	54.0	NA	NA	137-1968	5CB	PS
ZR-001A-C.	CONTROL DRUM POSITION	-102	CD 1	0.0	0-180DEG	5.0	F
ZR-001.-CA	CONTROL DRUM POSITION	-102	CD 1	0.0	0-180DEG	NAH	D
ZR-002A-C.	CONTROL DRUM POSITION	-102	CD 2	30.0	0-180DEG	500	F
ZR-002.-CA	CONTROL DRUM POSITION	-102	CD 2	30.0	0-180DEG	NAH	O
ZR-003A-C.	CONTROL DRUM POSITION	-102	CD 3	60.0	0-180DEG	5.0	F
ZR-003.-CA	CONTROL DRUM POSITION	-102	CD 3	60.0	0-180DEG	NAH	O

TABLE 4-1 (Continued)

MEASUREMENT CHANNEL	DESCRIPTION	LOCATION STA	RAD	THETA	SET-UP RANGE	SYS B/W	ST
ZR-304A-C.	CONTROL DRUM POSITION	-102	CD 4	90.0	0-180DEG	500	F
ZR-304.-CA	CONTROL DRUM POSITION	-102	CD 4	90.0	0-180DEG	NAM	D
ZR-305A-C.	CONTROL DRUM POSITION	-102	CD 5	120.0	0-180DEG	500	F
ZR-305.-CA	CONTROL DRUM POSITION	-102	CD 5	120.0	0-180DEG	NAM	D
ZR-306A-C.	CONTROL DRUM POSITION	-102	CD 6	150.0	0-180DEG	500	F
ZR-306.-CA	CONTROL DRUM POSITION	-102	CD 6	150.0	0-180DEG	NAM	D
ZR-307A-C.	CONTROL DRUM POSITION	-102	CD 7	180.0	0-180DEG	400	FC
ZR-307.-CA	CONTROL DRUM POSITION	-102	CD 7	180.0	0-180DEG	NAM	D
ZR-308A-C.	CONTROL DRUM POSITION	-102	CD 8	210.0	0-180DEG	400	F
ZR-308.-CA	CONTROL DRUM POSITION	-102	CD 8	210.0	0-180DEG	NAM	D
ZR-309A-C.	CONTROL DRUM POSITION	-102	CD 9	240.0	0-180DEG	400	F
ZR-309.-CA	CONTROL DRUM POSITION	-102	CD 9	240.0	0-180DEG	NAM	D
ZR-310A-C.	CONTROL DRUM POSITION	-102	CD10	270.0	0-180DEG	300	F
ZR-310.-CA	CONTROL DRUM POSITION	-102	CD10	270.0	0-180DEG	NAM	D
ZR-311A-C.	CONTROL DRUM POSITION	-102	CD11	300.0	0-180DEG	300	FC
ZR-311.-CA	CONTROL DRUM POSITION	-102	CD11	300.0	0-180DEG	NAM	D
ZR-312A-C.	CONTROL DRUM POSITION	-102	CD12	330.0	0-180DEG	300	F
ZR-312.-CA	CONTROL DRUM POSITION	-102	CD12	330.0	0-180DEG	NAM	D
ZR-100F-C.	AVG CONT DRUM POSITION	NA	NA	NA	0-180DEG	5C6	PSM
ZT-801.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 1	0.0	35-655 R	5 L	P
ZT-802.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 2	30.0	35-655 R	5 L	P
ZT-803.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 3	60.0	35-655 R	5 L	P
ZT-804.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 4	90.0	35-655 R	5 L	P
ZT-805.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 5	120.0	35-655 R	5 L	P
ZT-806.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 6	150.0	35-655 R	5 L	P
ZT-807.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 7	180.0	35-655 R	5 L	P
ZT-808.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 8	210.0	35-655 R	5 L	P
ZT-809.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD 9	240.0	35-655 R	5 L	P
ZT-810.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD10	270.0	35-655 R	5 L	P
ZT-811.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD11	300.0	35-655 R	5 L	P
ZT-812.-C.	DRUM TORQUE XDCR TEMP	-79.1	CD12	330.0	35-655 R	5 L	P
ZT-813.-C.	DRUM ACT BEARING UPPER	-89.0	CD 5	120.0	250-720R	5 L	P
ZT-814.-C.	DRUM ACT BEARING UPPER	-95.0	CD11	300.0	250-720R	5 L	P
ZT-815.-C.	SEAL RETAINER GAS TEMP	-69.0	CD 5	120.0	35-653.5	5 L	P
ZT-816.-C.	SEAL RETAINER GAS TEMP	-69.0	CD11	300.0	35-653.5	5 L	P
ZT-817.-C.	ACTUATOR FEEDBACK ASSY	-101	CD 5	120.0	250-720R	5 L	P
ZT-818.-C.	ACTUATOR FEEDBACK ASSY	-101	CD11	300.0	250-720R	5 L	P
ZT-819.-C.	DRUM ACTUATOR SEAL	-88.0	CD 5	120.0	250-720R	5 L	P
ZT-820.-C.	DRUM ACTUATOR SEAL	-88.0	CD11	300.0	250-720R	5 L	P
ZY-801.-C.	CONTROL DRUM TORQUE	-79.1	CD 1	0.0	+-350INP	500	F
ZY-802.-C.	CONTROL DRUM TORQUE	-79.1	CD 2	30.0	+-1K INP	500	F
ZY-803.-C.	CONTROL DRUM TORQUE	-79.1	CD 3	60.0	+-350INP	500	F
ZY-804.-C.	CONTROL DRUM TORQUE	-79.1	CD 4	90.0	+-1K INP	750	F
ZY-805.-C.	CONTROL DRUM TORQUE	-79.1	CD 5	120.0	+-350INP	750	F
ZY-805U-C.	CONTROL DRUM TORQUE	-79.1	CD 5	120.0	+-350INP	NAM	S
ZY-806.-C.	CONTROL DRUM TORQUE	-79.1	CD 6	150.0	+-1K INP	750	F
ZY-806U-C.	CONTROL DRUM TORQUE	-79.1	CD 6	150.0	+-1K INP	NAM	*
ZY-807.-C.	CONTROL DRUM TORQUE	-79.1	CD 7	180.0	+-350INP	750	F
ZY-808.-C.	CONTROL DRUM TORQUE	-79.1	CD 8	210.0	+-1K INP	750	F
ZY-809.-C.	CONTROL DRUM TORQUE	-79.1	CD 9	240.0	+-350INP	750	F
ZY-810.-C.	CONTROL DRUM TORQUE	-79.1	CD10	270.0	+-1K INP	750	F
ZY-811.-C.	CONTROL DRUM TORQUE	-79.1	CD11	300.0	+-350INP	750	F
ZY-811U-C.	CONTROL DRUM TORQUE	-79.1	CD11	300.0	+-350INP	NAM	S
ZY-812.-C.	CONTROL DRUM TORQUE	-79.1	CD12	330.0	+-1K INP	750	F
ZY-812U-C.	CONTROL DRUM TORQUE	-79.1	CD12	330.0	+-1K INP	NAM	*

TABLE 4-2

SELECTED FACILITY INSTRUMENTATION LIST

GB-001. -CJ	G1 Open/Closed Limit Indication
GB-002. CJ	G2 Open/Closed Limit Indication
GB-003. CH	G3 Closed Limit Indication
GB-003Y-CH	G-3 Transfer Switch Position Indication
GB-011. -CB	G-11 Open/Closed Limit Indication
GB -013. -CH	G-13 Closed Limit Indication
GB-013Y-CH	G-13 Transfer Switch Position Indication
GC-001. -CJ	G-1 GH_2 Supply Line Valve Command
GC-002. -CJ	G-2 GN_2 Supply Line Valve Command
GC-003. -CH	G-3 Gas Propellant Pressure Valve Command
GC-003B-CH	G-3 Hold Closed Command
GC-011. -CY	G-11 Helium Supply Valve Command
GC-013. -CH	G-13 Helium Pressure Valve Command
GC-013B-CH	G-13 Hold Closed Command
GP-002. -CE	Line Pressure Upstream of G-3
GP-004. -C	Gas Pressure GF-4 Venturi
GP-004D-C	GF-4 Venturi Differential Pressure
GP-014. -CE	Helium Pressure Downstream of G-13
GP-014D-C	GF-14 Venturi Differential Pressure
GR-001. -CJ	G-1 Stem Position
GR-002. -CJ	G-2 Stem Position
GR-003A-CH	G-3 Stem Position
GR-013A-CH	G-13 Stem Position
HA-004. -C	Turbine Axial Acceleration
HA-014. -C	Turbine Radial Acceleration
HB-050. -CB	H-50 Open/Close Limit Indication
HB-053. -CH	H-53 Close Limit Indication
HB-053Y-CH	H-53 Transfer Command Indication
HB-060. -CH	H-60 Close Limit Indication
HB-060Y-CH	H-60 Transfer Command Indication
HB-150. -CB	H-150 Open/Close Limit Indication

TABLE 4-2 (Continued)

HC-050. -CB	H-50 GH_2 to Turbine Valve Command
HC-053. -CH	H-53 High Pressure GH_2 to Turbine Valve Command
HC-060. -CH	H-60 NFS-3 Turbine Control Valve Command
HC-060P-CH	H-60 Turbine Flow Control Valve Scram Command
HC-150. -CB	H-150 GH_2 Vent Valve Turbine Startup Command
HF-591U-C	Pump Turbine Flowmeter
HP-053. -C	Turbine Bottle Supply Pressure
HP-060. -C	Turbine LH_2 Supply Pressure
HP-007. -C	Turbine Inlet Pressure
HP-075. -C	Turbine Cavity Pressure
HP-501. -C	Pump Inlet Pressure
HP-511. -C	Balance Piston Bleed Pressure
HP-520. -C	Turbine Exit Gas Pressure
HP-521. -C	Pump Discharge Pressure
HP-575. -C	Interseal Bleed Pressure
HQ-590. -C	LH_2 Pump Speed
HQ-590A-C	LH_2 Pump Speed, Backup
HR-053A-CH	H-53 Stem Position
HR-060A-CH	H-60 Stem Position
HT-060. -C	Turbine GH_2 Supply Temperature
HT-501. -C	Pump Inlet Temperature
HT-511. -C	Balance Piston Bleed Temperature
HT-521. -C	Pump Discharge Temperature
HT-921. -C	Turbine Exit Gas Temperature
IV-001. -C	Program No. 1 Output, L-11
IV-002. -C	Program No. 2 Output High Pressure Dewar Flow
IV-003. -C	Program No. 3 Output G-3 Flow
IV-004. -C	Program No. 4 Output Control Drums
IV-005. -C	Program No. 5 Output Program Power
IV-006. -C	Program No. 6 Output Reactor Temperature
IV-007. -C	X-53 - X-161 Program Output
IV-203U-C	Period Demand
IV-204U-C	Chamber Temperature Demand
IV-205U-C	Power Demand
IV-207. -C	Temperature Controller Output

TABLE 4-2 (Continued)

KB-001.-CJ	K-1 Open/Closed Limit Indication
KB-002.-CJ	K-2 Open/Closed Limit Indication
KB-003.-CB	K-3 Open/Closed Limit Indication
KB-006.-CH	K-6 Open/Closed Limit Indication
KB-006Y-CH	K-6 Transfer Switch Position Indication
KB-007.-CB	K-7 Open/Closed Limit Indication
KB-050.-CB	K-50 Open/Closed Limit Indication
KB-053.-CH	K-53 Closed Limit Indication
KB-053Y-CH	K-53 Transfer Switch Position Indication
KB-061.-CB	K-61 Open/Closed Limit Indication
KB-062.-CB	K-62 Open/Closed Limit Indication
KB-103.-CP	K-103 Open/Closed Limit Indication
KB-106.-CP	K-106 Open/Closed Limit Indication
KB-107.-CP	K-107 Open/Closed Limit Indication
KC-001.-CJ	K-1 Dewar 4 Flow Control Valve Command
KC-002.-CJ	K-2 Dewar 5 Flow Control Valve Command
KC-003.-CB	K-3 Combined Dewar Outlet Valve Command
KC-006.-CH	K-6 LH_2 Flow Control Valve Command
KC-006A-CH	K-6 Servo Command
KC-007.-CB	K-7 Mixing Chamber Discharge Valve Command
KC-050.-CB	K-50 Main GH_2 Shutoff Valve Command
KC-053.-CH	K-53 Servo Amp Command Input Dewar Pressure Valve End
KC-061.-CB	K-61 Dewar 4 Pressurizing Shutoff Valve Command
KC-062.-CB	K-62 Dewar 5 Pressurizing Shutoff Valve Command
KC-063.-CP	K-103 LH_2 Cooldown Vent Valve Command
KC-106.-CP	K-106 LH_2 Cooldown Vent Valve Command
KC-107.-CP	K-107 Mixing Chamber Chilldown Line Valve Command
KC-107B-CP	K-107 Hold Close Command
KF-005U-C	Mixing Chamber LH_2 Analog Flow Rate
KL-001.-C	Dewar 4 Level - Reflectometer
KL-002.-C	Dewar 5 Level - Reflectometer
KP-003.-C	LH_2 Pressure Upstream of K-3
KP-005.-C	LH_2 Pressure Upstream of Mixing Chamber Supply Orifice
KP-005D-CE	KF-5 Venturi Differential Pressure

TABLE 4-2 (Continued)

KP-007.-C	Mixing Chamber Discharge Line Pressure
KP-053.-C	Dewar Pressurization Control Pressure
KP-061.-CE	Dewar 4 Storage Pressure
KP-062.-CE	Dewar 5 Storage Pressure
KR-006A-CH	K-6 Stem Position
KR-053A-CH	K-53 Stem Position
KR-103A-CP	K-103 Stem Position
KR-106A-CP	K-106 Stem Position
KR-107A-CP	K-107 Stem Position
KT-001.-C	Dewar 4 Outlet Temperature
KT-002.-C	Dewar 5 Outlet Temperature
KT-005.-C	Temperature Upstream of KF-5
~~KT-005N-C~~	~~Temperature Upstream of KF-5, Narrow Range~~
KT-007.-CE	Mixing Chamber Discharge Temperature
KT-007N-C	Mixing Chamber Discharge Temperature, Narrow Range
KT-071.-C	Dewar 4 Temperature at 2900 lb level
KT-072.-C	Dewar 5 Temperature at 2900 lb level
KT-106.-C	K-106 Vent Temperature at K-6
KT-107.-C	K-107 Vent Temperature at K-7
KT-107N-C	K-107 Vent Temperature at K-7, Narrow Range
KV-007V-CL	Total Mixing Chamber Flow Demand
KV-500V-CL	GH_2/LH_2 Ratio Demand
KX-001.-C	Dewar 4 Level - Carbon Resistor
KX-002.-C	Dewar 5 Level - Carbon Resistor
LB-001.-C	L-1 Open/Closed Limit Indication
LB-002.-C	L-2 Open/Closed Limit Indication
LB-003.-CJ	L-3 Open/Closed Limit Indication
LB-011.-CH	L-11 Closed Limit Indication
LB-011Y-CH	L-11 Transfer Command Indication
LB-050.-CB	L-50 Open/Closed Limit Indication
LB-053.-CH	L-53 Closed Limit Indication
LB-053Y-CH	L-53 Transfer Command Indication
LB-061.-CB	L-61 Open/Closed Limit Indication
LB-062.-CB	L-62 Open/Closed Limit Indication
LB-103.-CB	L-103 Open/Closed Limit Indication
LB-109.-CH	L-109 Close Limit Indication

TABLE 4-2 (Continued)

LB-109Y-CH	L-109 Transfer Command Indication
LB-111.-CH	L-111 Open/Close Limit Indication
LB-151.-CB	L-151 Open/Close Limit Indication
LB-251.-CB	L-251 Open/Close Limit Indication
LC-001.-C	L-1 Dewar 1 Outlet Valve Command
LC-002.-C	L-2 Dewar 2 Outlet Valve Command
LC-003.-C	L-3 LH_2 Supply Valve Command
LC-011.-CH	L-11 Servo Command
LC-011A-CH	L-11 Servo Valve Hold Open Command
LC-011B-CH	L-11 Hold Close Command
LC-050.-CB	L-50 Dewar Pressurization Line Block Valve Command
LC-053.-CH	L-53 Dewars 1 and 2 Pressure Control Valve Command
LC-061.-CB	L-61 Dewar 1 Pressure Valve Command
LC-062.-CB	L-62 Dewar 2 Pressure Valve Command
LC-103.-CB	L-103 Propellant Inlet Line Vent Valve Command
LC-109.-CH	L-109 LH_2 Flow Bypass Valve Command
LC-111.-CH	L-111 Mail LH_2 Line Chilldown Vent Valve Command
LC-11B-C	L-111 Hold Close Command
LC-151.-CB	L-151 LH_2 Dewar Pressurization from Storage Valve Command
LC-251.-CB	L-251 LH_2 Dewar Pressurization Restricted Flow Valve Command
LF-010U-C	L-10 LH_2 Computed Flow Rate
LL-001.-C	Dewar 1 Level Indicator, Reflectometer
LL-002.-C	Dewar 2 Level Indicator, Reflectometer
LP-003.-C	LH_2 Line Pressure Upstream of L-3
LP-004.-C	Pressure Upstream of Inlet Venturi LF-4
LP-004D-C	LF-4 Inlet Venturi Delta Pressure
LP-010.-C	Pressure Upstream of Discharge Venturi LF-10
LP-010D-C	LF-10 Discharge Venturi Delta Pressure
LP-011D-C	Delta Pressure Across L-11
LP-012.-C	Nozzle Supply Pressure
LP-012A-C	Nozzle Supply Pressure
LP-012B-C	Nozzle Supply Pressure
LP-052.-C	Dewars 1 and 2 GH_2 Supply Pressure
LP-052D-C	Differential Pressure Across LF-52
LP-061.-CE	Dewar 1 Pressure
LP-062.-CE	Dewar 2 Pressure

TABLE 4-2 (Continued)

LR-001.-CJ	L-1 Stem Position
LR-002.-CJ	L-2 Stem Position
LR-003.-CJ	L-3 Stem Position
LR-011A-CH	L-11 Stem Position
LR-053A-C	L-53 Stem Position
LR-109A-CH	L-109 Stem Position
LR-111A-CH	L-111 Stem Position
LT-001.-C	Dewar 1 LH_2 Outlet Temperature
LT-002.-C	Dewar 2 LH_2 Outlet Temperature
LT-010.-C	LH_2 Temperature Upstream of Discharge Venturi FL-10
LT-012.-C	Nozzle Supply Temperature
LT-052-C	Dewars 1 and 2 GH_2 Supply Temperature
LT-071.-C	Dewar 1 Temperature at 5800 lb level
LT-072.-C	Dewar 2 Temperature at 5800 lb level
LT-081.-C	Dewar 1 Temperature at 29,000 lb level
LT-082.-C	Dewar 2 Temperature at 29,000 lb level
LT-109.-C	L-109 LH_2 Discharge Skin Temperature
LT-111.-C	Main LH_2 Line Chilldown Vent Temperature
LT-111N-C	Main LH_2 Line Chilldown Vent Temperature, Narrow Range
LV-102P-C	Average Nozzle Supply Pressure
LX-001.-C	Dewar 1 Level-Carbon Resistor
LX-002.-C	Dewar 2 Level-Carbon Resistor
NB-001.-CB	N-1 Open/Close Limit Indication
NB-002.-CB	N-2 Open/Close Limit Indication
NB-002.-CB	N-3 Open/Close Limit Indication
NB-011.-CP	N-11 Open/Close Limit Indication
NB-021.-CP	N-21 Open/Close Limit Indication
NB-030.-CB	N-30 Open/Close Limit Indication
NB-050.-CB	N-50 Open/Close Limit Indication
NB-053.-CP	N-53 Close Limit Indication
NB-061.-CB	N-61 Open/Close Limit Indication
NB-062.-CB	N-62 Open/Close Limit Indication
NB-063.-CB	N-63 Open/Close Limit Indication
NB-110.-CB	N-110 Open/Close Limit Indication
NB-130.-CB	N-130 Open/Close Limit Indication
NB-221.-CB	N-221 Open/Close Limit Indication

TABLE 4-2 (Continued)

NC-001.-CB	N-1 Dewar 6 Outlet Valve Command
NC-002.-CB	N-2 Dewar 7 Outlet Valve Command
NC-003.-CB	N-3 Dewar 8 Outlet Valve Command
NC-011.-CP	N-11 RCV No. 1 Flow Control Valve Command
NC-021.-CP	N-21 RCV No. 2 Flow Control Valve Command
NC-030.-CB	N-30 GN_2 Cooldown Supply Valve Command
NC-050.-CB	N-50 LN_2 Dewar Pressurization Line Block Valve Command
NC-053.-CP	N-53 LN_2 Dewar Pressurization Valve Command
NC-061.-CB	N-61 Dewar 6 Pressure Supply Valve Command
NC-062.-CB	N-62 Dewar 7 Pressure Supply Valve Command
NC-063.-CB	N-63 Dewar 8 Pressure Supply Valve Command
NC-110.-CP	N-110 RCV Chilldown Vent Valve Command
NC-130.-CB	N-130 GN_2 Cooldown Vent Supply Valve Command
NC-221.-CB	N-221 RCV Inlet Bypass Valve Command
NP-001D-C	Dewar 6 Delta Pressure Level Indication
NP-002D-C	Dewar 7 Delta Pressure Level Indication
NP-003D-C	Dewar 8 Delta Pressure Level Indication
NP-004.-C	RCV LN_2 Supply Pressure
NP-010D-CE	PCV No. 1 LN_2 Inlet Venturi Delta Pressure (NF-10)
NP-011D-C	N-11 Delta Pressure
NP-020D-C	RCV No. 2 LN_2 Inlet Venturi Delta Pressure (NF-20)
NP-021D-C	N-21 Delta Pressure
NP-030.-C	RCV GN_2 Discharge Line Pressure
NP-061.-CE	Dewar 6 Pressure
NP-062.-CE	Dewar 7 Pressure
NP-063.-CE	Dewar 8 Pressure
NR-011.-C	N-11 Stem Position
NR-021.-C	N-21 Stem Position
NR-053A-CP	N-53 Stem Position
NR-110.-CP	N-110 Stem Position
NT-004.-C	LN_2 Dewar Supply Temperature
NT-001.-C	RCV No. 1 LN_2 Inlet Temperature
NT-021.-C	RCV No. 2 LN_2 Inlet Temperature
NT-022.-C	RCV No. 2 LN_2 Discharge Temperature
NT-110-C	N-110 Vent Temperature
NT-110N-C	N-110 Vent Temperature, Narrow Range
NT-130N-C	GN_2 Cooldown Vent Temperature

TABLE 4-2 (Continued)

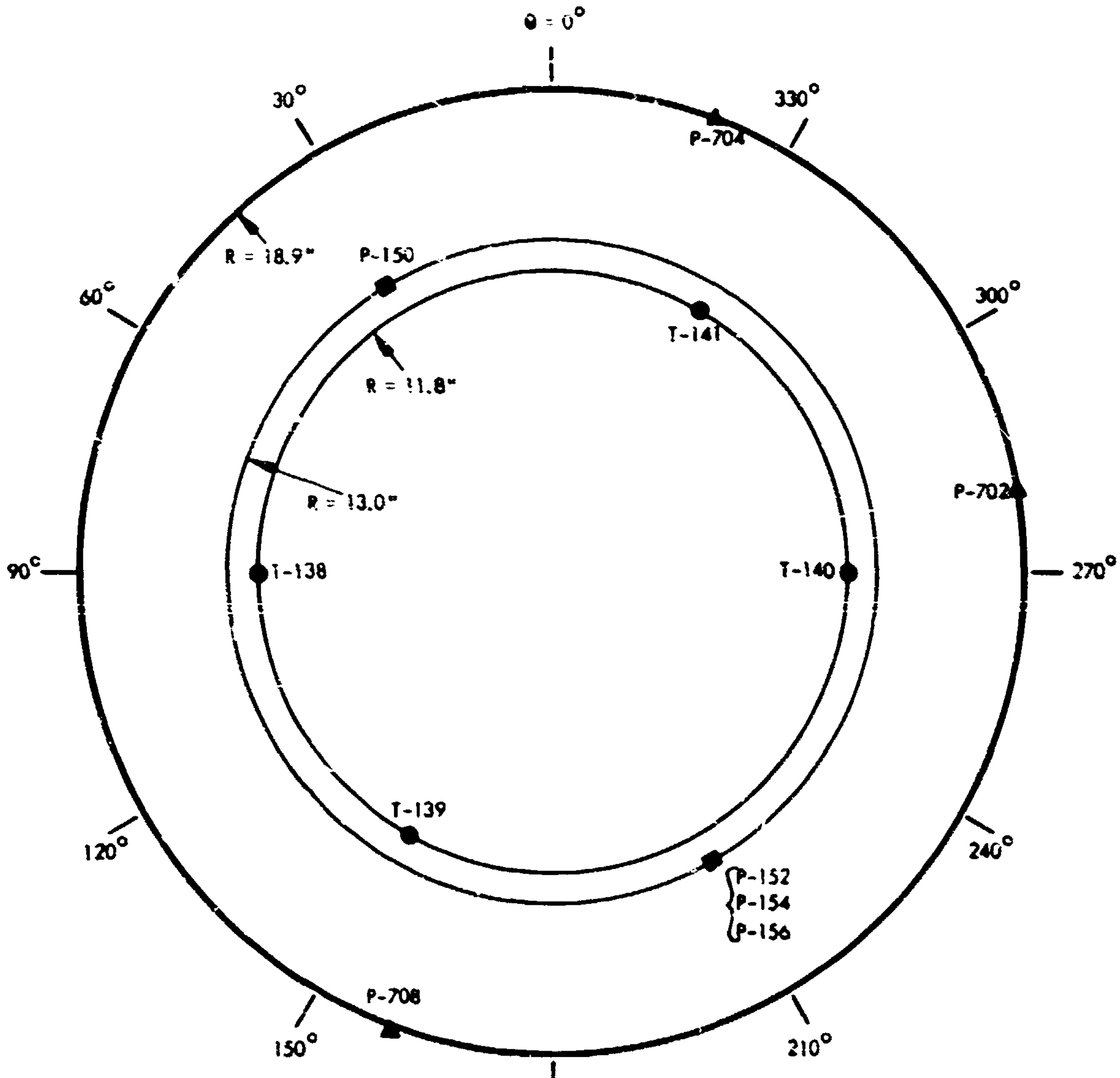
QB-001. -CB	Q-1 Open/Closed Limit Indication
QB-002. -CB	Q-2 Open/Closed Limit Indication
QB-003. -CB	Q-3 Open/Closed Limit Indication
QB-004. -CB	Q-4 Open/Closed Limit Indication
QB-005. -CB	Q-5 Open/Closed Limit Indication
QB-006. -CB	Q-6 Open/Closed Limit Indication
QB-007. -CB	Q-7 Open/Closed Limit Indication
QB-008. -CB	Q-8 Open/Closed Limit Indication
QB-009. -CB	Q-9 Open/Closed Limit Indication
QB-010. -CB	Q-10 Open/Closed Limit Indication
QB-011. -CB	Q-11 Open/Closed Limit Indication
QB-012. -CB	Q-12 Open/Closed Limit Indication
QP-020. -C	Helium Header Supply Pressure
~~QP-030. -C~~	~~GH_2 Pressure Upstream of K-50~~
QP-040. -C	N_2 Run Supply Header Pressure
QC-001. -CB	Q-1 Bottle 1 Shutoff Valve Command
QC-002. -CB	Q-2 Bottle 2 Shutoff Valve Command
QC-003. -CB	Q-3 Bottle 3 Shutoff Valve Command
QC-004. -CB	Q-4 Bottle 4 Shutoff Valve Command
QC-005. -CB	Q-5 Bottle 5 Shutoff Valve Command
QC-006. -CB	Q-6 Bottle 6 Shutoff Valve Command
QC-007. -CB	Q-7 Bottle 7 Shutoff Valve Command
QC-008. -CB	Q-8 Bottle 8 Shutoff Valve Command
QC-009. -CB	Q-9 Bottle 9 Shutoff Valve Command
QC-010. -CB	Q-10 Bottle 10 Shutoff Valve Command
QC-011. -CB	Q-11 Bottle 11 Shutoff Valve Command
QC-012. -CB	Q-12 Bottle 12 Shutoff Valve Command
SB-410S-C	Fixed Power Scram Indication
SB-411S-C	Floating Power Scram Indication
SB-412S-C	Period Scram Indication
SM-001. -C	Linear No. 1 Analog Range Indication
SM-002. -C	Lenear No. 2 Analog Range Indication
SN-011. -C	Linear Power No. 1, Block No. 2
SN-012. -C	Linear Power No. 2, Block No. 2
SN-013S-C	Selected Linear Power
SN-021. -C	Log Power No. 1, Block No. 2

TABLE 4-2 (Continued)

SN-021A-C	Log Power No. 2, Block No. 2	
SN-022.-C	Log Power No. 3, Block No. 1	
SN-022A-C	Log Power No. 4, Block No. 1	
SN-023S-C	Selected Log Power	
SN-031W-C	Wide Band Log Power 1	
SN-032W-C	Wide Band Log Power 2	
SN-061.-C	Power Period No. 1	
SN-062.-C	Power Period No. 2	
SN-063.-C	Power Period No. 3	
SN-064.-C	Power Period No. 4	
SN-065E-C	Expanded Period	
SN-065S-C	Selected Power Period	
XB-001.-CB	X-1	Open/Closed Limit Indication
XB-003.-CB	X-3	Open/Closed Limit Indication
~~XB-017.-CB~~	~~X-17~~	~~Open/Closed Limit Indication~~
XB-018.-CB	X-18	Open/Closed Limit Indication
XB-019.-CB	X-19	Open/Closed Limit Indication
XB-020.-CB	X-20	Open/Closed Limit Indication
XB-021.-CB	X-21	Open/Closed Limit Indication
XB-022.-CB	X-22	Open/Closed Limit Indication
XB-050.-CB	X-50	Open/Closed Limit Indication
XB-053.-CH	X-53	Close Limit Indication
XB-053Y-CH	X-53	Transfer Switch Position Indication
XB-061.-CB	X-61	Open/Closed Limit Indication
XB-101.-CB	X-101	Open/Closed Limit Indication
XB-103.-CH	X-103	Open/Closed Limit Indication
XB-203.-CB	X-203	Open/Closed Limit Indication
XC-001.-CB	X-1	High Pressure Dewar Outlet Valve Command
XC-003.-CB	X-3	High Pressure Dewar Discharge Valve Command
XC-017.-CB	X-17	High Pressure Dewar Bottle No. 1 Shutoff Valve Command
XC-018.-CB	X-18	High Pressure Dewar Bottle No. 2 Shutoff Valve Command
XC-019.-CB	X-19	High Pressure Dewar Bottle No. 3 Shutoff Valve Command
XC-020.-CB	X-20	High Pressure Dewar Bottle No. 4 Shutoff Valve Command
XC-021.-CB	X-21	High Pressure Dewar Bottle No. 5 Shutoff Valve Command
XC-022.-CB	X-22	High Pressure Dewar Bottle No. 6 Shutoff Valve Command
XC-050.-CB	X-50	Dewar 3 Pressure Supply Valve Command
XC-053.-CH	X-53	High Pressure Dewar Pressure Control Valve Command

TABLE 4-2 (Continued)

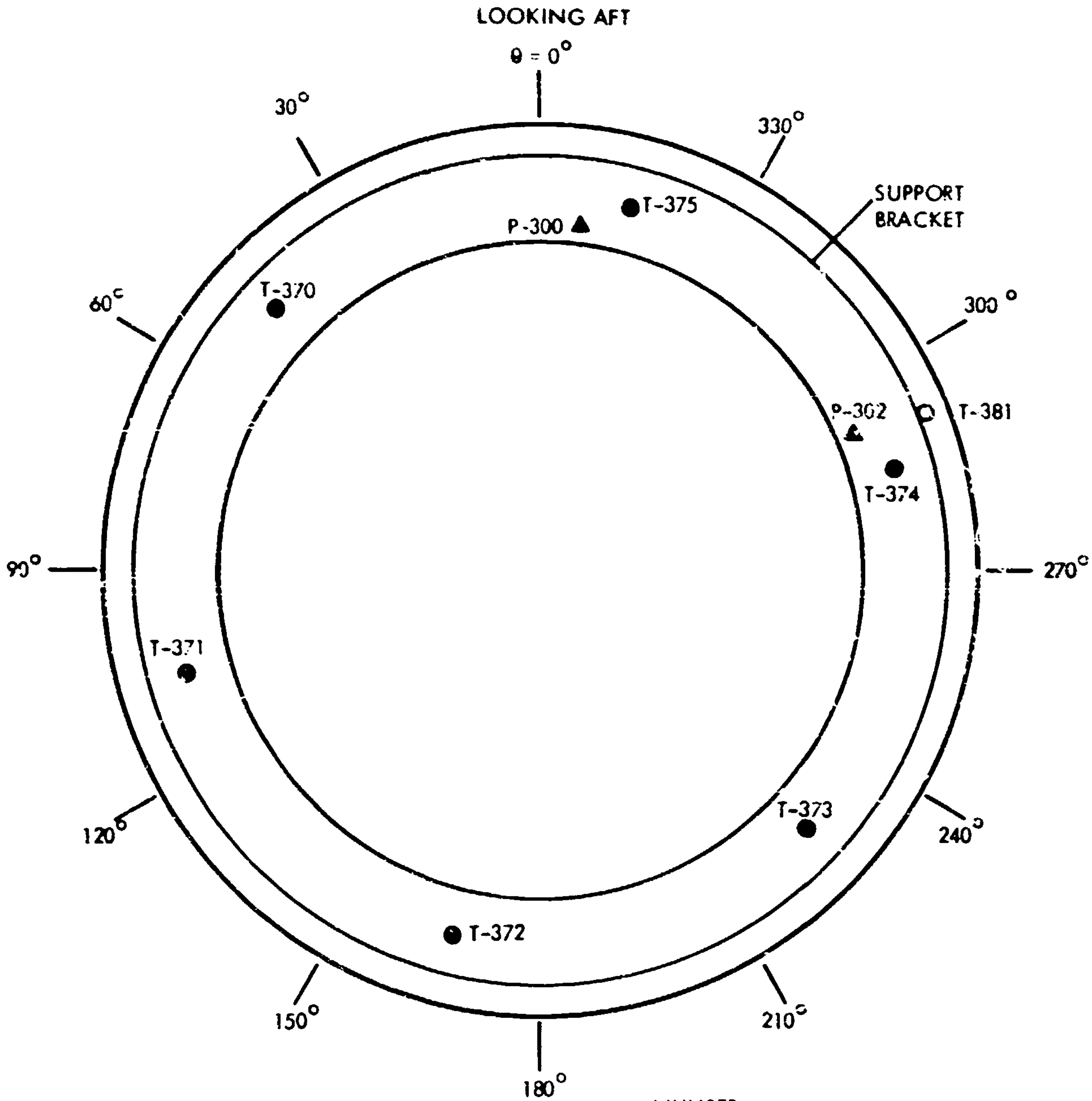
XC-053B-CH	X-53 Hold Close Command
XC-061.-CB	X-61 HP Dewar Pressurization Valve Command
XC-101.-CB	X-101 HP Dewar Delivery Line Vent Valve Command
XC-103.-CH	X-103 HP Dewar Discharge Line Vent Valve Command
XC-103B-CH	X-103 Hold Close Command
XC-203.-CB	X-203 HP Dewar Restricted Main Line Fill Valve Command
XP-002.-C	HP Dewar Discharge Line Pressure
XP-002D-C	HP Dewar Discharge Orifice Delta Pressure
XP-053.-C	HP Dewar Pressurization Supply Pressure
XP-061.-CE	HP Dewar Pressure
XR-053A-CH	X-53 Stem Position
XR-103A-CH	X-103 Stem Position
XT-002.-C	HP Dewar Discharge Temperature
XT-102.-C	Discharge Line Skin Temp. Upstream of X-103
XT-103.-C	HP Dewar Discharge Line Vent Temperature



SYMBOL	MEASUREMENT	STATION	NUMBER OF PROBES
●	TEMPERATURE (W/WR)	68.5	4
■	PRESSURE	70.0	2
▲	PRESSURE	50.8	3

611680-38

Figure 4-1. NRX-A6 Nozzle Chamber and Core Exit Plenum Measurements

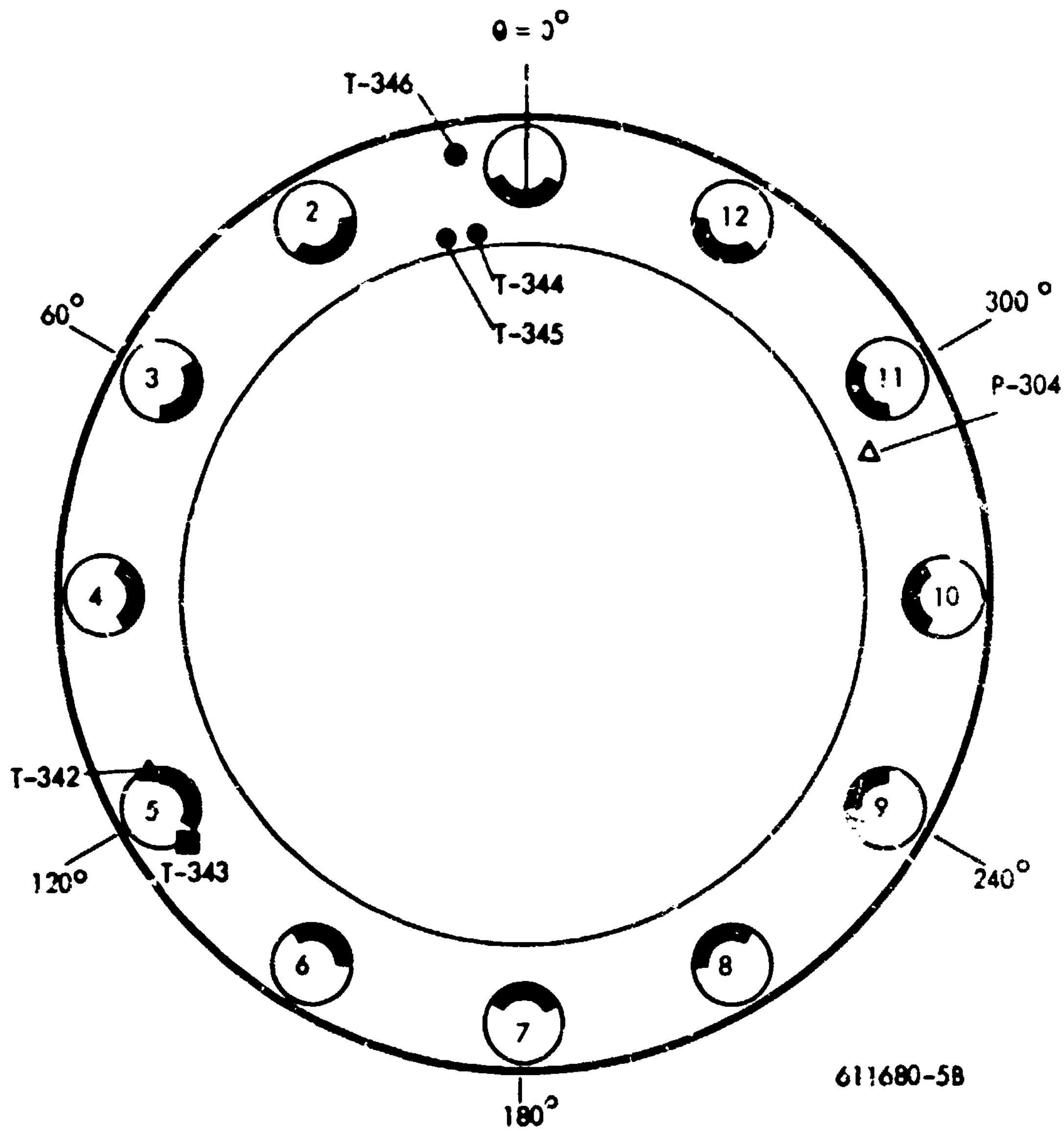


SYMBOL	MEASUREMENT	STATION	NUMBER OF PROBES
●	TEMPERATURE (RRT)	53.3	6
○	TEMPERATURE (C/C)	53.2	1
▲	PRESSURE	52.5	2

611680-1B

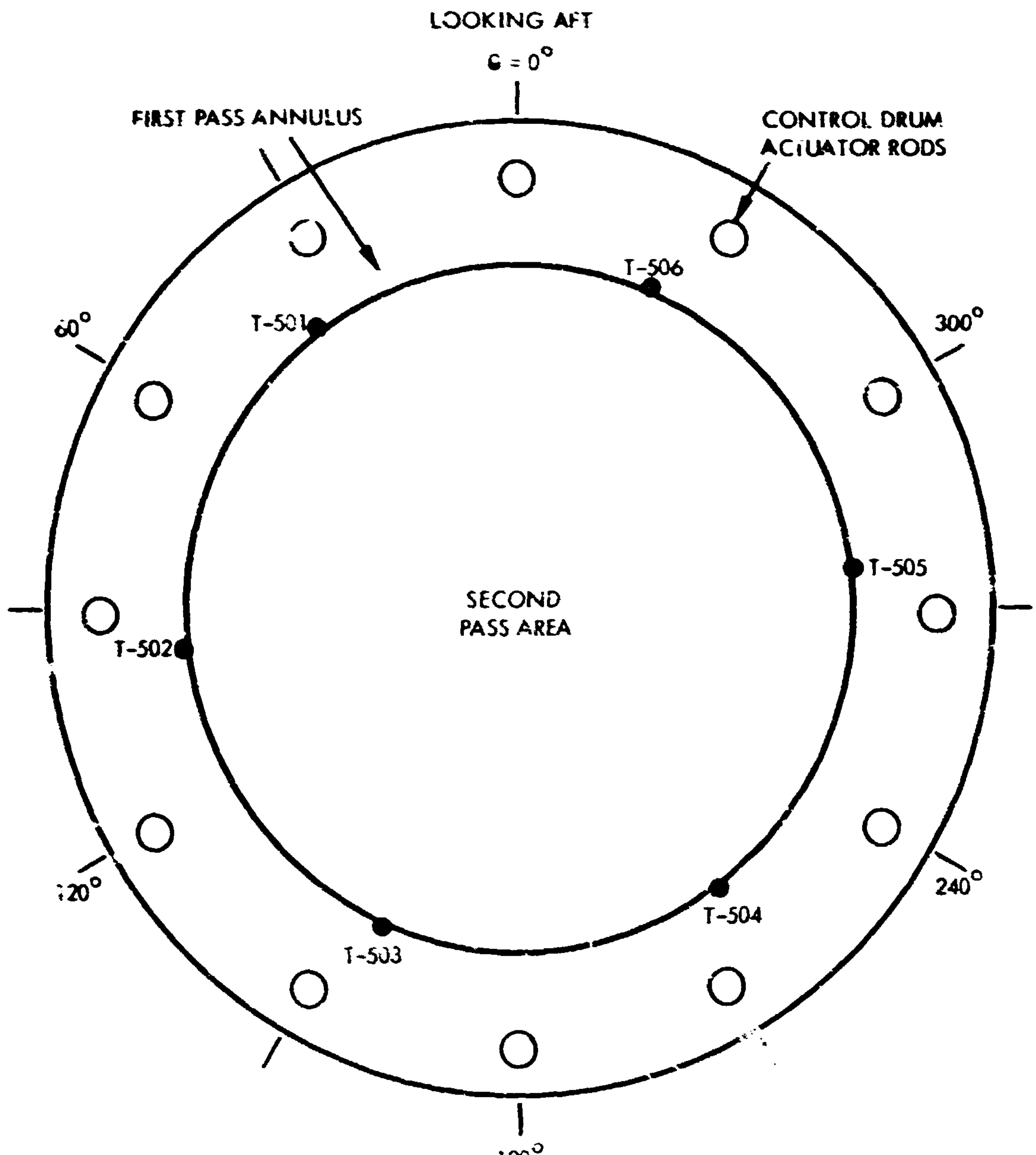
Figure 4-2. NRX-A6 Reflector Inlet Plenum Measurements Locations

Astronuclear Laboratory



SYMBOL	MEASUREMENT	STATION	TOTAL NUMBER
●	REFLECTOR CYLINDER EXIT GAS TEMPERATURE	0.0, -0.1	3
▲	DRUM VANE EXIT GAS TEMPERATURE	-0.9	1
■	DRUM ANNULUS EXIT GAS TEMPERATURE	-0.9	1
△	REFLECTOR OUTLET PLENUM PRESSURE	-0.4	1

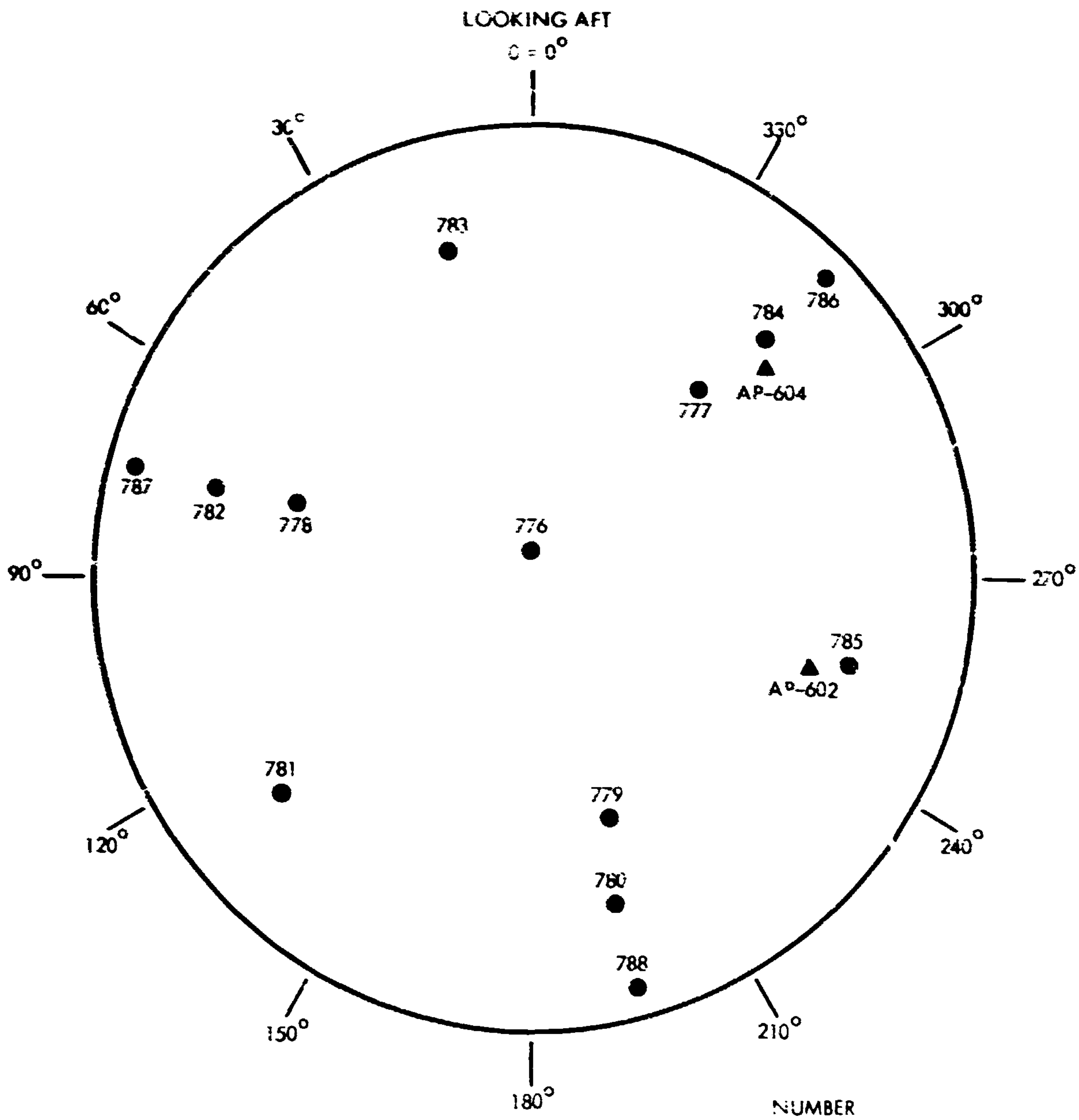
Figure 4-3. NRX-A6 Reflector Outlet Plenum Measurement Locations



SYMBOL	MEASUREMENT	STATION	NUMBER OF PROBES
●	TEMPERATURE (COPPER/CONSTANTAN)	-23.3	6

611630-2B

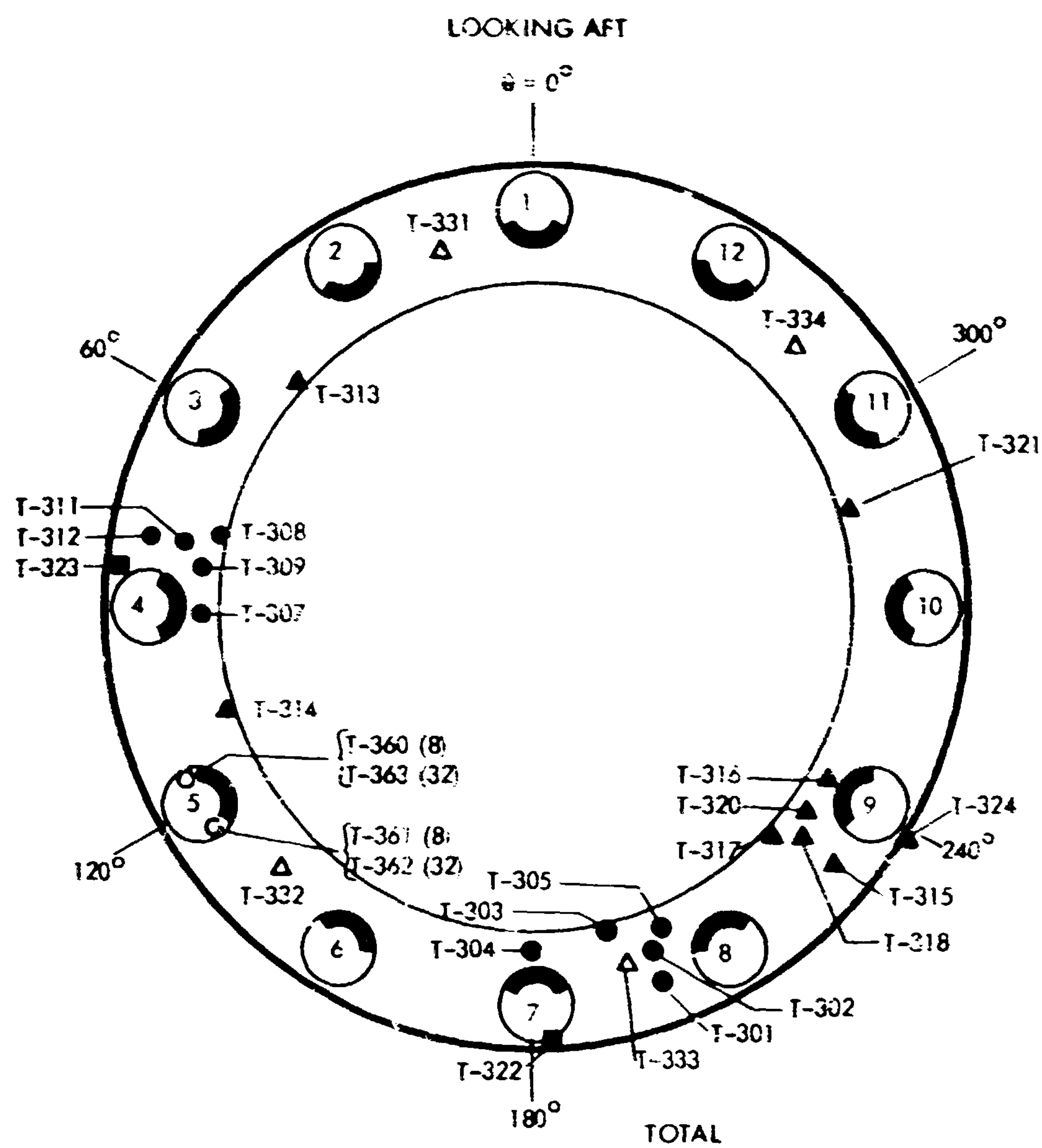
Figure 4-4. NRX-A6 Shield Dome End Plenum Measurement Locations



SYMBOL	MEASUREMENT	STATION	NUMBER OF PROBES
●	TEMPERATURE (COPPER/CONSTANTAN)	-0.8	13
▲	PRESSURE	-0.8	2

611680-4B

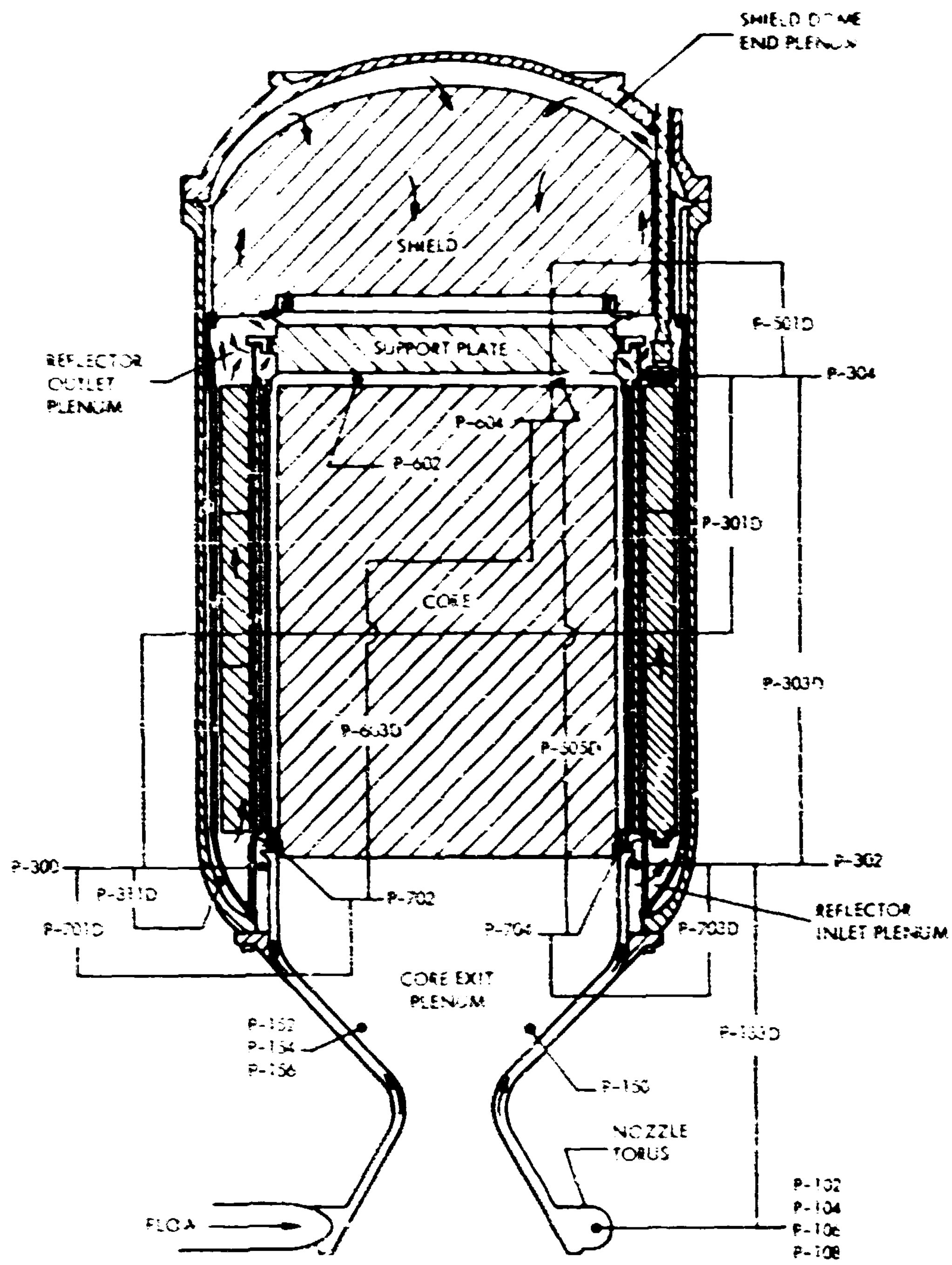
Figure 4-5. NRX-A6 Core Inlet Plenum Measurement Locations



SYMBOL	MEASUREMENT	STATION	TOTAL NUMBER
●	REFLECTOR CYLINDER	21.0-21.4	10
▲	REFLECTOR CYLINDER	50.5-51.1	9
■	REFLECTOR CYLINDER	17.2	2
O	CONTROL DRUM	8.0, 32.0	4
Δ	REFLECTOR BOLT	25.7	4

611680-6B

Figure 4-6. NRX-A6 Measurement Locations Reflector and Control Drum Material Temperatures



PRESSURE MEASUREMENTS IN LATERAL SUPPORT SYSTEM ARE SHOWN IN FIGURE 4-9

Figure 4-7. NRX-A6 Pressure Measurement Locations

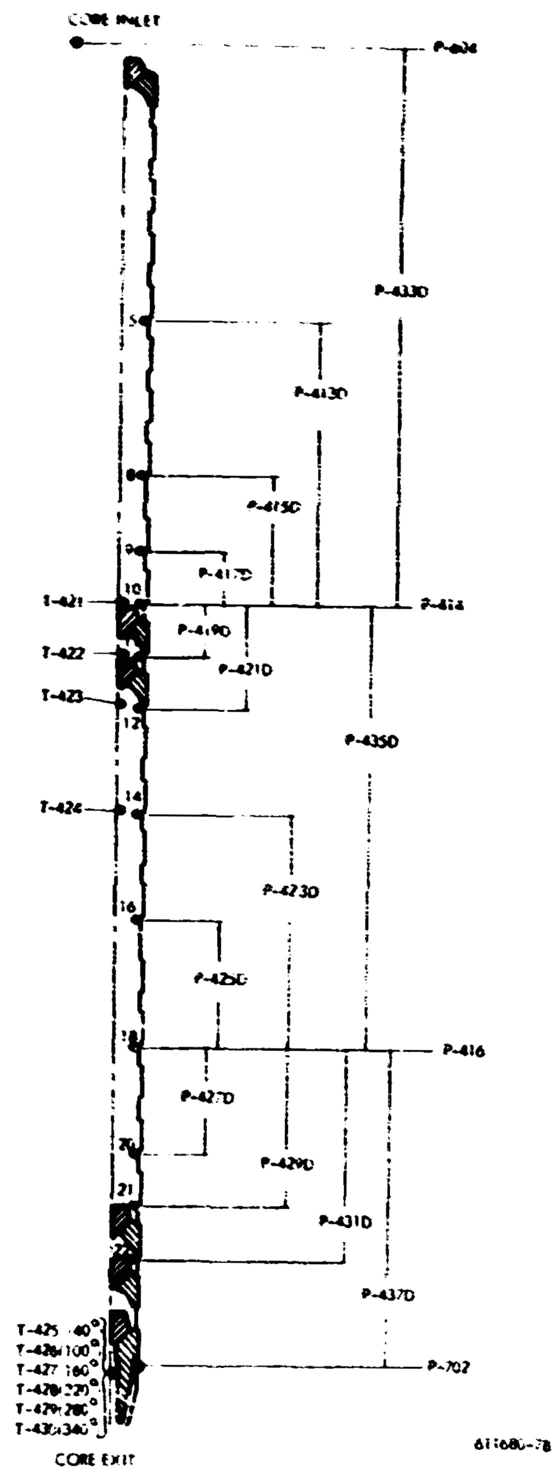


Figure 4-8. NRX-A6 Measurement Locations Lateral Support System

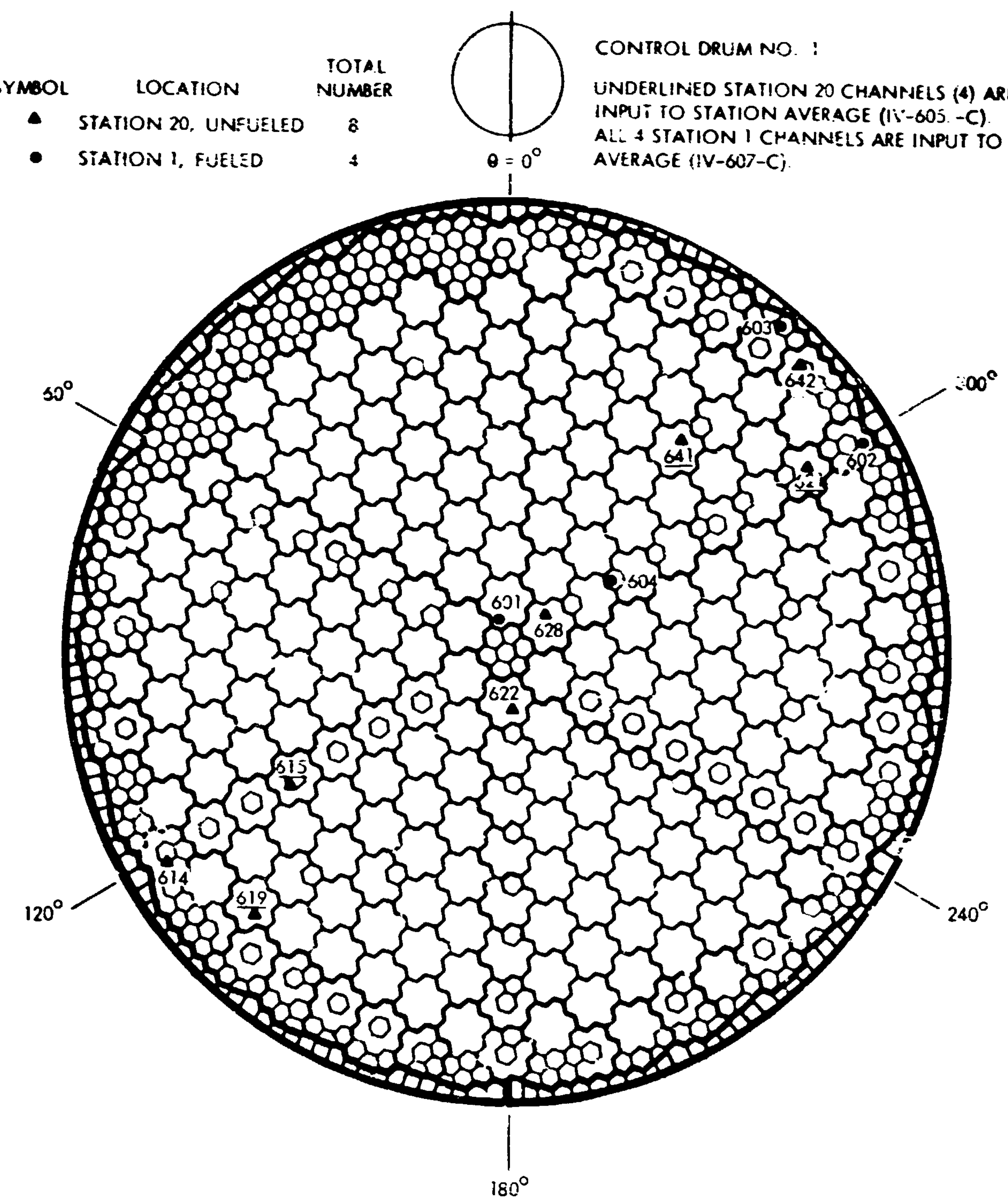


Figure 4-9. NRX-A6 Core Measurement Locations Stations 1 and 20 Thermocouples

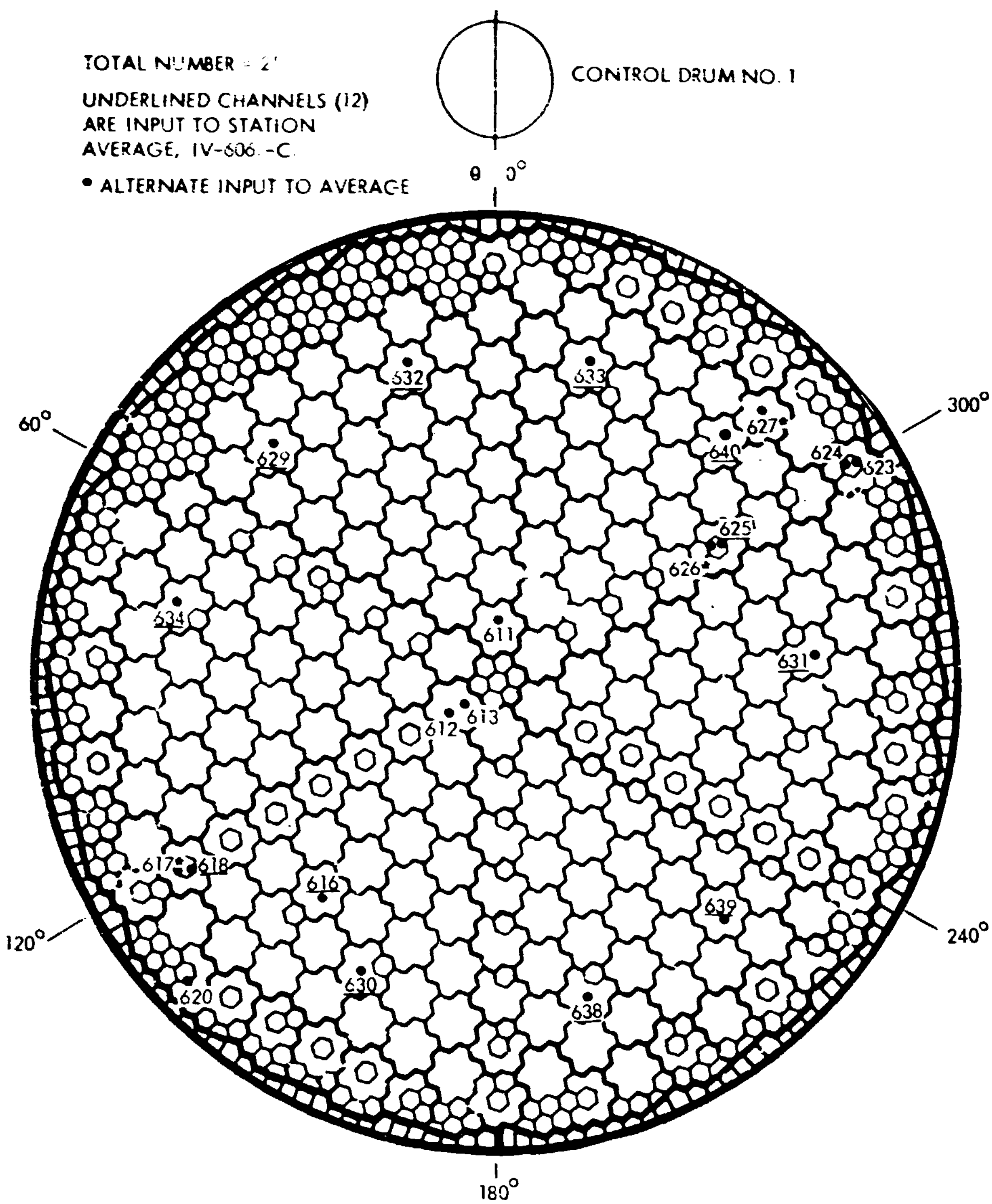


Figure 4-10. NRX-A6 Core Measurement Locations Station 26 Thermocouples

SYMBOL	LOCATION	TOTAL NUMBER	AVERAGE CHANNEL
▲	CLUSTER EXIT GAS	21	IV-680.-C.
●	TIE ROD EXIT MTL	10	IV-710.-C.

CONTROL DRUM NO. 1

CLUSTER EXIT GAS T/C'S ARE ROUTED THROUGH CENTRAL UNFUELED ELEMENTS WITH TIPS CENTERED AT EXIT OF FUELED ELEMENTS.

UNDERLINED CHANNELS ARE INPUT TO AVERAGE. SIX INPUTS PER AVERAGE CHANNEL.
*ALTERNATE INPUT TO AVERAGE

θ = 0°

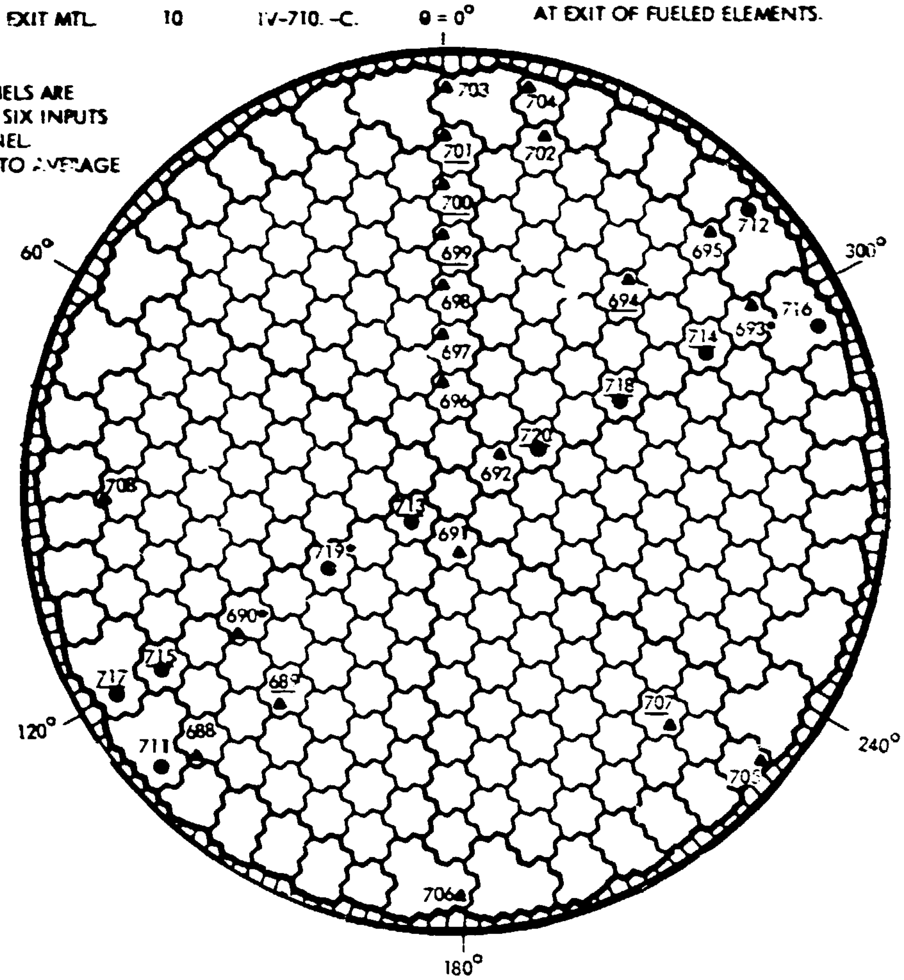


Figure 4-11. NRX-A6 Core Measurement Locations Cluster Exit Gas and Tie Rod Exit Material Thermocouples

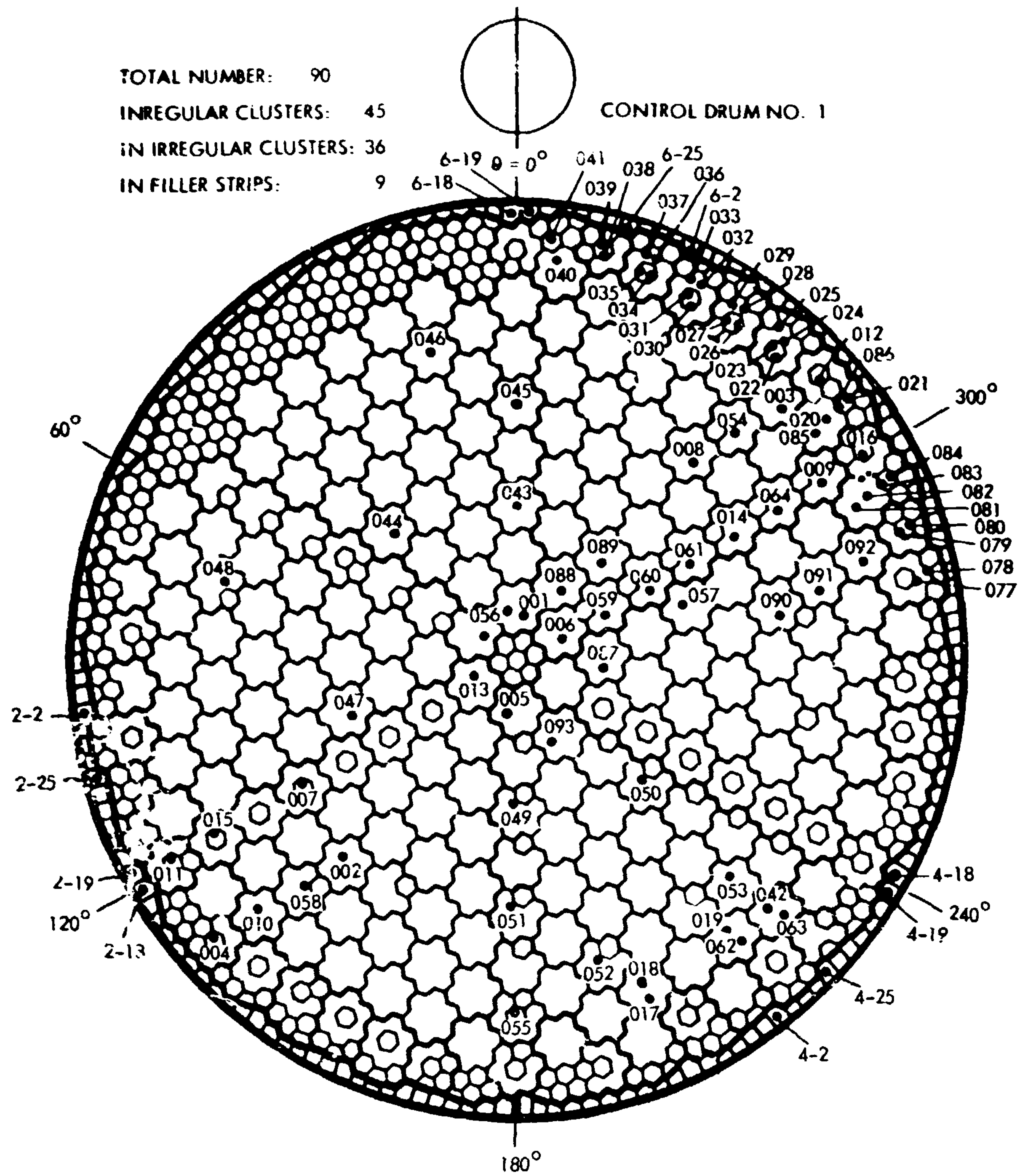


Figure 4-12. NRX-A6 Core Measurement Locations Thermal Capsules

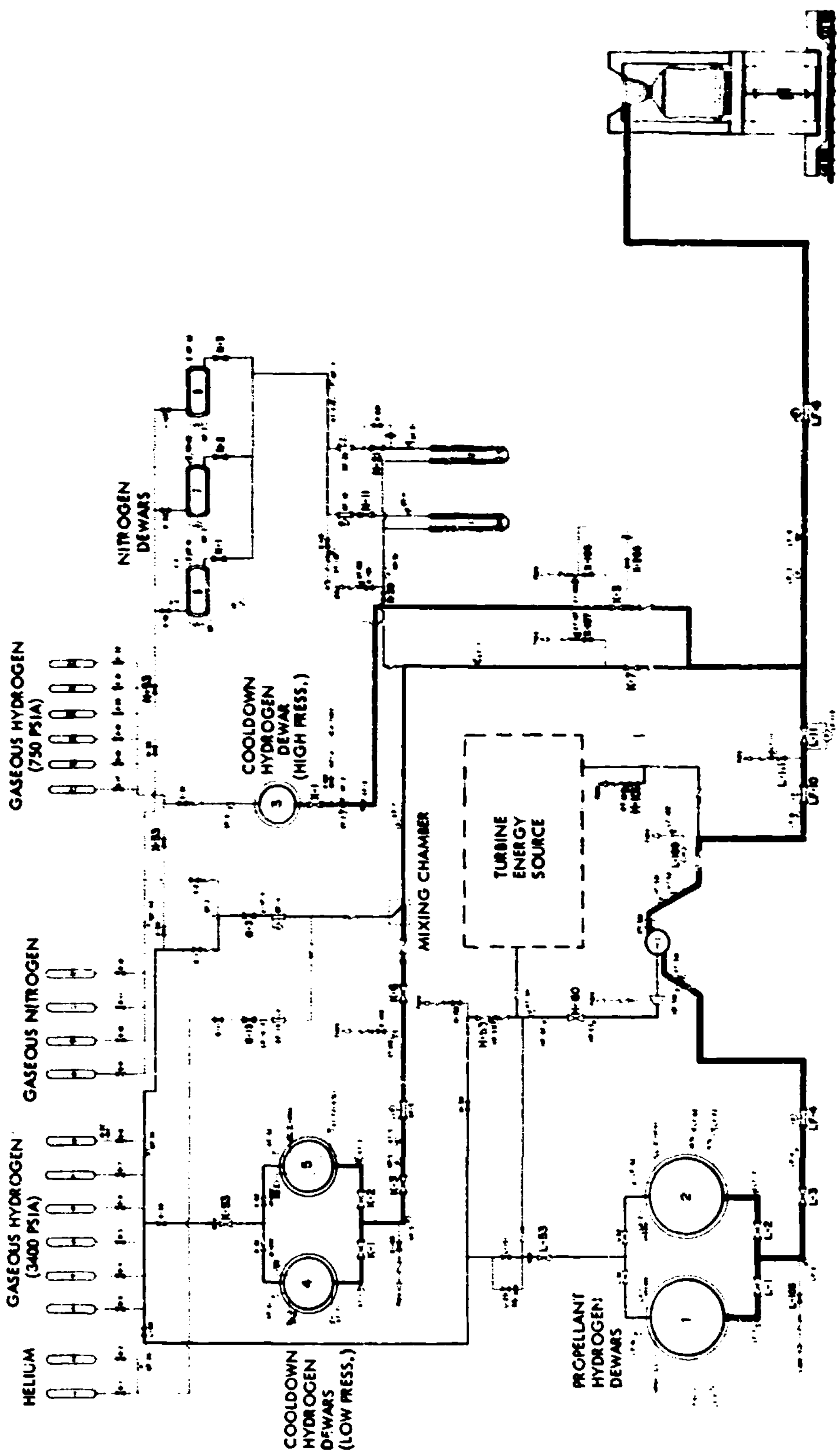


Figure 4-13. Test Cell "C" Simplified Flow Schematic

5.0 NEUTRONIC SYSTEM TESTS

5.1 Poison Wire Removal Operations

5.1.1 Objective

The objective of these operations is to effect complete poison wire removal (6207 peripheral and 783 central for a total of 6990 wires) at the MAD facility and to assure that an adequate shutdown margin exists, as defined by the NRX-A6 Test Specification[1] and the NRX-A6 Safety Evaluation Report [19].

5.1.2 Operational Limits

Shutdown Margin

The assurance of a shutdown margin of at least 2.00$ shall be established before each withdrawal increment[1].

Number of Wires Per Increment

During peripheral poison wire removal operations the number of wires to be removed in each increment is limited to the smaller of either 1) ten percent of the original poison wire inventory of 6990 wires or 2) ten percent of the number of wires (to the nearest whole cluster) which, if removed, would lead to violation of the shutdown margin limit.

During central wire removal operations (783 wires)*, the number of wires to be removed per increment is limited to the smaller of 1) fifteen percent of the original number of central wires or 2) fifteen percent of the number (to the nearest whole cluster)[12] which, if removed, would lead to violation of the shutdown margin limit.

5.1.3 Predictions

Predictions during poison wire removal operations have been separated into two parts, peripheral and central wire removal.

*The presence of exit gas thermocouples which shadow 15 central coolant channels reduced the central poison wire inventory from the usual 798 to 783. The reduction was made in clusters 4A1, 6A1 and 1B1, each of which now contain 37 wires.

Peripheral Wire Removal

This first group of predictions for the peripheral poison wire removal is taken from NRX-A5 measurements reported in Reference 13. The following discussion describes the basis for this prediction.

Shown in Figure 5-1 is a schematic of the source/detector geometry which is planned for use during all wire removal operations[14]. Comparison of this geometry with that used during peripheral wire removal on NRX-A5 (see Figure C-2 of Reference 13) indicates that only one detector, C-2*, was in the geometry of detector B in Figure 5-1. The predicted inverse multiplication curve, shown in Figure 5-2, has, therefore, been taken to be the response of NRX-A5 detector C-2*. In principle, a small modification for the expected difference in shutdown of the two reactors should be made. However, the differences are small and would not result in a noticeable change in the curve.

Central Wire Removal

During central wire removal at the MAD facility, the shutdown reactivity margin will be monitored by two methods:

1) a graphical approach based on the curve of inverse multiplication as a function of poison wire content, and

2) a numerical technique based on the measured source neutron multiplication rate with (1) the control drum bank at zero and (2) one drum at 180 degrees, eleven drums at zero.

The predicted behavior is discussed below.

Inverse Multiplication Method

The NRX-A6 is designed to be shutdown by 3.78$* with control drums alone before installation in the test cell, so it is expected that removal of all poison wires will not lead to criticality. Therefore, when neutron multiplication data taken during wire removal (with the

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*Based on a delayed critical drum bank position of 91 degrees (with the shields withdrawn and empty) and a control drum bank span of 7.4$.

control drum bank at 0 degrees) are plotted in the standard inverse multiplication form, as shown in Figure 5-3, the extrapolation to criticality will indicate removal of more poison wires than are actually present. The apparent shutdown may then be calculated (assuming the wire worth is about 1.0¢ per wire) by subtracting the number of wires removed from the total number of wires which, if removed, would lead to criticality. The predicted inverse multiplication measurements are shown in Figure 5-3 and the predicted shutdown in Figure 5-4. Figure 5-5, developed from data taken during the NRX-A2, NRX-A3, and NRX/EST[20] test series, shows the variation of the worth of clusters of poison wires with poison wire content.

Numerical Technique

A method has been developed to estimate the shutdown during poison wire withdrawal from an extended inverse multiplication approach.[15] In this method, inverse multiplication measurements are made during wire removal (1) with all control drums at 0 degrees and (2) with one drum at 180 degrees and the rest at 0 degrees. The inverse multiplication prediction is shown in Figure 5-3. The shutdown is calculated from these two measurements with the following formula:

$$K_{SD} = \frac{\Delta \rho}{\beta[1 - 2\Delta\rho - R(1 - \Delta\rho)]}$$

where

K_{SD} is the shutdown in \$,

$\frac{\Delta \rho}{\beta}$ is the worth of one control drum = 0.617\$*,

$\Delta \rho = 0.00438$, and

$$R = \frac{C_o}{C_1} = \frac{\text{count rate with drums fully inserted}}{\text{count rate with one drum fully withdrawn}}.$$

*Recent measurements at WANEF using the NRX-A6 reflector indicate 0.664$ for the average worth of one drum

The predicted shutdown is shown in Figure 5-4. NRX-A5 experience has shown that this technique is conservative when the reactor is deeply shutdown and provides a good quantitative estimate as the unpoisoned condition is approached. With all poison wires removed, the calculated NRX-A5 shutdown was 18¢ less than later criticality measurements indicated.[16]

5.2 Initial Criticality

5.2.1 Objective

The major objectives of this operation are the attainment of initial criticality and the measurement of the delayed critical drum bank position in four configurations:

1) with the facility shields empty and withdrawn from the reactor,

2) with the facility shields empty and in place around the reactor,

3) with the facility shields in place around the reactor and filled with plain water, and

4) with the facility shields in place around the reactor and filled with borated water.

5.2.2 Test Limits

The maintenance of a minimum shutdown margin of 2.00$ requires that the reactor come to delayed critical at a drum bank position greater than 63 degrees based on a drum bank span of 7.4$ and a reactor temperature of $540^{o} \pm 35^{o}$R.

5.2.3 Predictions

The NRX-A6 delayed critical position with all poison wires removed is expected to be 91 ± 8* degrees with the facility shields withdrawn and empty. The change in system reactivity expected to result from movement of the dry shields into place around the reactor has been calculated to be -46¢. When plain water is added to the shields in this configuration, an additional increase in reactivity of 22¢ is expected. When this water is borated, the

*This corresponds to the previous ± 7 degrees uncertainty. The increase results from the lower NRX-A6 drum span.

reactivity decreases by 47¢. These reactivity changes are based on a group of LASL experiments[17], adjusted for differences between the experiments and the NRX-A6 configuration by the technique described in Reference 18. The expected delayed critical positions in each of these various configurations is shown in table 5-1.

The NRX-A6 reactor will be brought to initial criticality remotely, by incremental outward rotation of the control drum bank and concurrent standard inverse multiplication measurements. The predicted change in inverse multiplication with drum position is shown in Figure 5-6 for the configuration with shields withdrawn and empty. In the event that shutdown limitations require poison wires to be present at this time, the inverse multiplication curve of the system will be modified. Figure 5-7 shows how the predicted inverse multiplication changes if one or two clusters of poison wires are present (each with 42 wires). This was developed by use of Figure 5-5 to estimate the additional shutdown that would result from the presence of the wires. Note that the abscissae of Figures 5-6 and 5-7 are linear in reactivity and assume a cosine relation between drum position and reactivity.

5.3 Control Drum Calibration

5.3.1 Objective

The objectives of this operation are (1) to measure individually the integral worth of two control drums and (2) to measure the differential control drum bank worth near the critical position. Both tests are to be accomplished after (1) complete poison wire removal and (2) closing and filling of the side shields with borated water.

5.3.2 Test Limits

Reactivity insertions shall be limited in magnitude to that which would result in a minimum positive period of 0.3 seconds.

5.3.3 Test Plan

Individual Integral Drum Worth

The integral worth of two control drums shall be determined individually in a manner which approximates the following:

1) With eleven drums grouped as a bank and held at the 0 degree position, the selected drum to be calibrated shall be rotated from 0 degrees to 180 degrees and held at that angle.

2) Utilizing the eleven drum bank, criticality shall be established such that the rate-of-change of linear power does not exceed 5 percent per minute. The bank position shall then be held.

3) The selected drum shall then be rotated from 180 degrees to 0 degrees and all drum positions held for at least 30 seconds.

4) Utilizing again the eleven drum bank, criticality shall be re-established such that the rate-of-change of linear power does not exceed 5 percent per minute, and the bank position held.

5) The selected drum shall then be rotated from 0 degrees to 180 degrees and all drum positions held. The reactor shall be allowed to stabilize for several doubling times to determine the positive period.

6) Steps 1) to 5) shall be repeated twice more for a total of three times.

7) Steps 1) to 6) shall be repeated for the second drum.

Differential Control Drum Bank Worth

At least two duplicate measurements of the differential control drum bank worth shall be made near the critical drum bank position. These shall be obtained by introducing a positive reactivity change of about 70¢ and allowing the reactor to stabilize for several doubling times.

5.3.4 Predictions

The predicted integral drum bank worth for the NRX-A6 reactor is 7.4 $\pm$ 0.3\$. The integral worth of a single drum is one-twelfth of this or 61.7 $\pm$ 2.5¢. Thus, the single drum rotations in Steps 3 and 5 of the previous section should result in reactivity changes of 61.7 $\pm$ 2.5¢. If linear power is trimmed until the variation does not exceed 5.0 percent per minute prior to the drum movement, the error in measured reactivity will be less than

TABLE 5-1

PREDICTED DRUM POSITION BY CONFIGURATION

Configuration (All Poison Wires Removed)	Predicted Delayed Critical Drum Bank Position, Degrees*
Shields Withdrawn and Empty	91 ± 8
Shields Together and Empty	84 ± 8
Shields Together and Filled With Plain Water	81 ± 8
Shields Together and Filled With Borated Water	88 ± 8

---

*There are in fact differences in the uncertainties attached to the various shield configurations. However, when the shield worth uncertainties are added statistically to the uncertainty in the inherent reactivity of the NRX-A6 reactor (± 55¢), the total uncertainty is the same to the nearest degree.

approximately ± 1.0¢. Thus, if linear power is held within the above tolerance, the scatter in the worth measurements of the drum selected for calibration should be approximately ± 1.0¢ about some average value which is expected to be in the range 61.7 ± 2.5¢ (59.2 to 64.2¢). Presented in Figure 5-8 is the period-reactivity relationship to allow correction of non-equilibrium conditions.

The predicted differential worth of the control drum bank is shown in Figure 5-9. In the test system configuration to be used here, criticality is expected at 88 degrees ± 8 degrees (See table 5-1) so that the specified[1] 70¢ positive reactivity change will require outward drum bank rotations of about 11 degrees.

Figure 5-10 shows the predicted integral control drum bank worth variation with bank position.

5.4 Neutronic Power Calibration

The initial neutronic power calibration for the NRX-A5 reactor will be performed by one of two methods. The primary calibration technique will involve the use of in-core gold wires placed in a central module fuel element coolant channel as described in the NRX-A5 prediction report (Reference 7). These gold wires are, in turn, calibrated by exposure of identical wires in PAX-E at WANEF, where a complete mapping of the fission distribution and an absolute normalization to fission rate by a radiochemical technique was employed. The exact description of this procedure will not be included here since the experimental data are not available at this time. Instead, the description and the accompanying data for this procedure will be contained in a supplement to this report when these data become available.

The secondary calibration technique involves the use of sulfur pellets calibrated at the PAX reactor facility at WANEF by exposure near the nozzle throat position with a simulated test cell "C" facility shield in place. The test cell "C" shield is simulated by use of the NRX-A3 Privy Roof Mounted Shield, containing 1.7% borated water and placed adjacent to the PAX reactor as shown in figure 5-11. Specifically, sulfur in the form of pressed pellets 0.25 inches thick and 1.5 inches in diameter, positioned approximately 2.0 inches below the nozzle throat position (coordinates R - 7.3", station 80", and $\theta = 240^{o}$) is exposed during the low power neutronics calibration run and is then counted following this run to determine its activity. Appropriate corrections are made for decay following the run and the activity is corrected to saturation. Finally, this saturated activity time is converted to neutron flux $E > 2.9$ Mev by comparison with sulfur pellets calibrated in a Triga reactor.

These data are used to obtain the thermal power calibration by using the conversion factor

$$P \text{ (watts)} = \frac{\phi}{1.10 \times 10^4}$$

where ϕ is the neutron flux for energy $E > 2.9$ Mev.

This calibration assumes a conversion factor from fission rate to thermal power of 3.23×10^{10} fissions/sec-w.

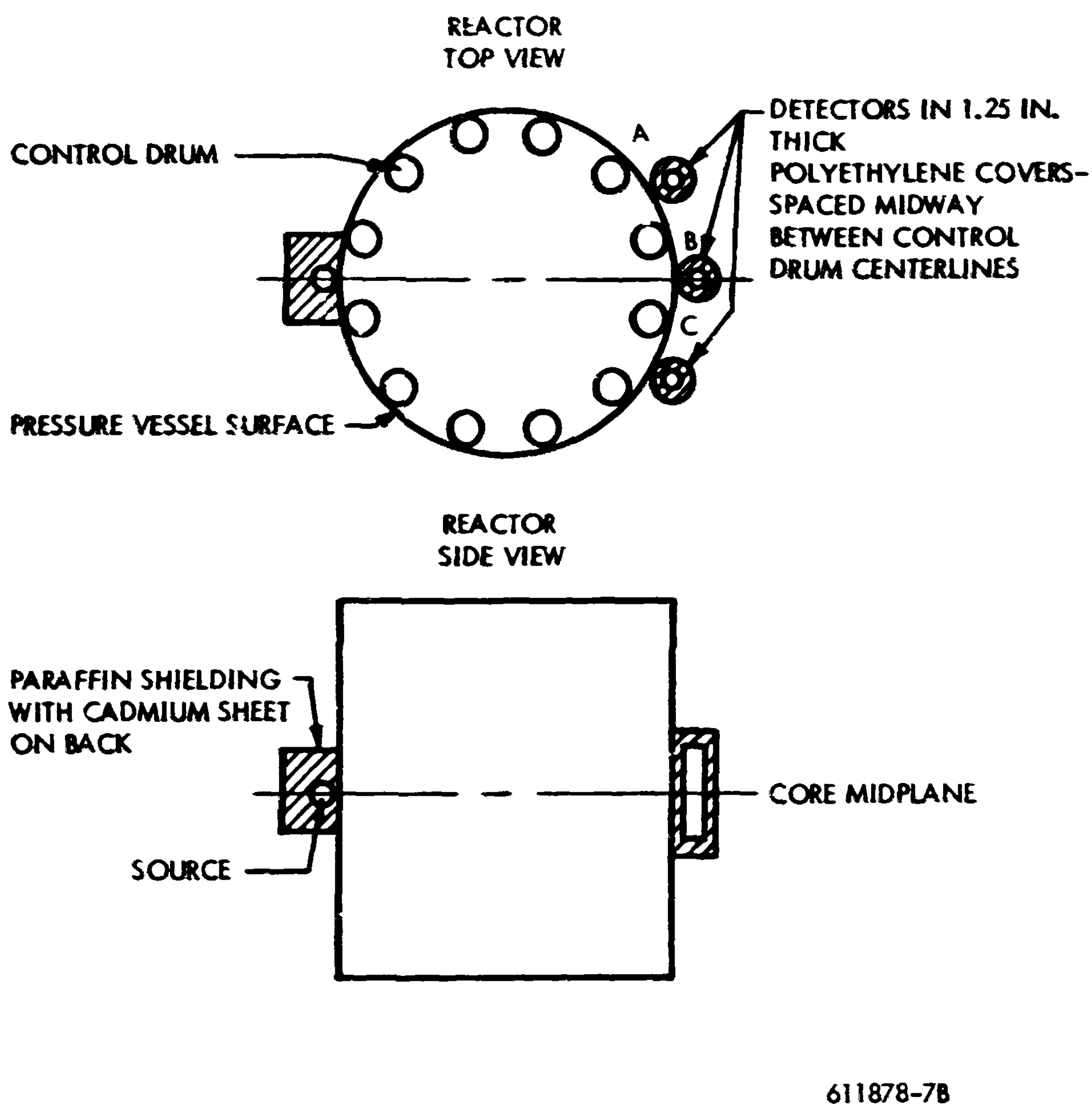

Figure 5-1. Source-Reactor-Detector Geometry for Peripheral and Central Poison Wire Removal

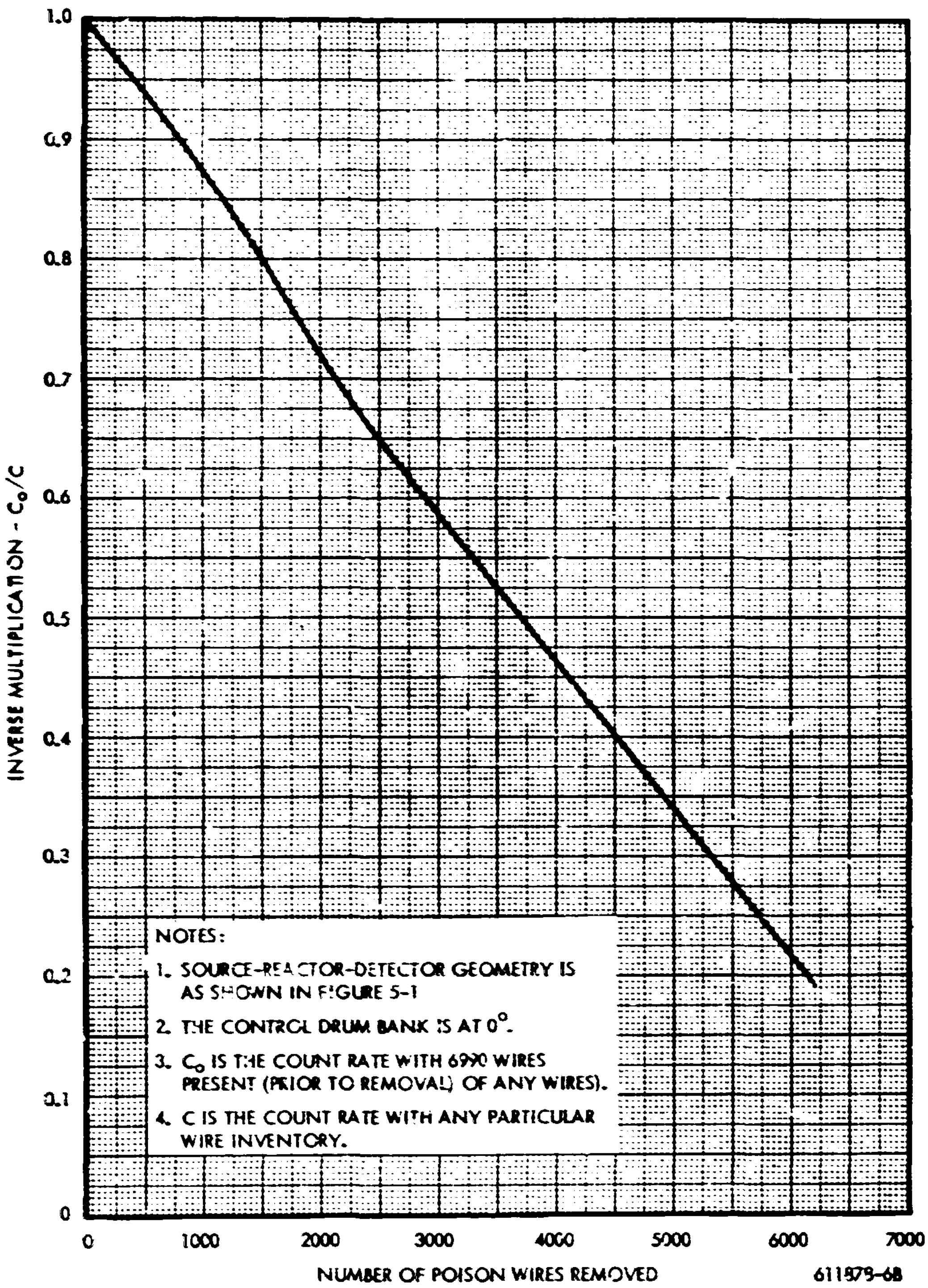

Figure 5-2. Predicted Inverse Multiplication for NRX-A6 Peripheral Poison Wire Removal

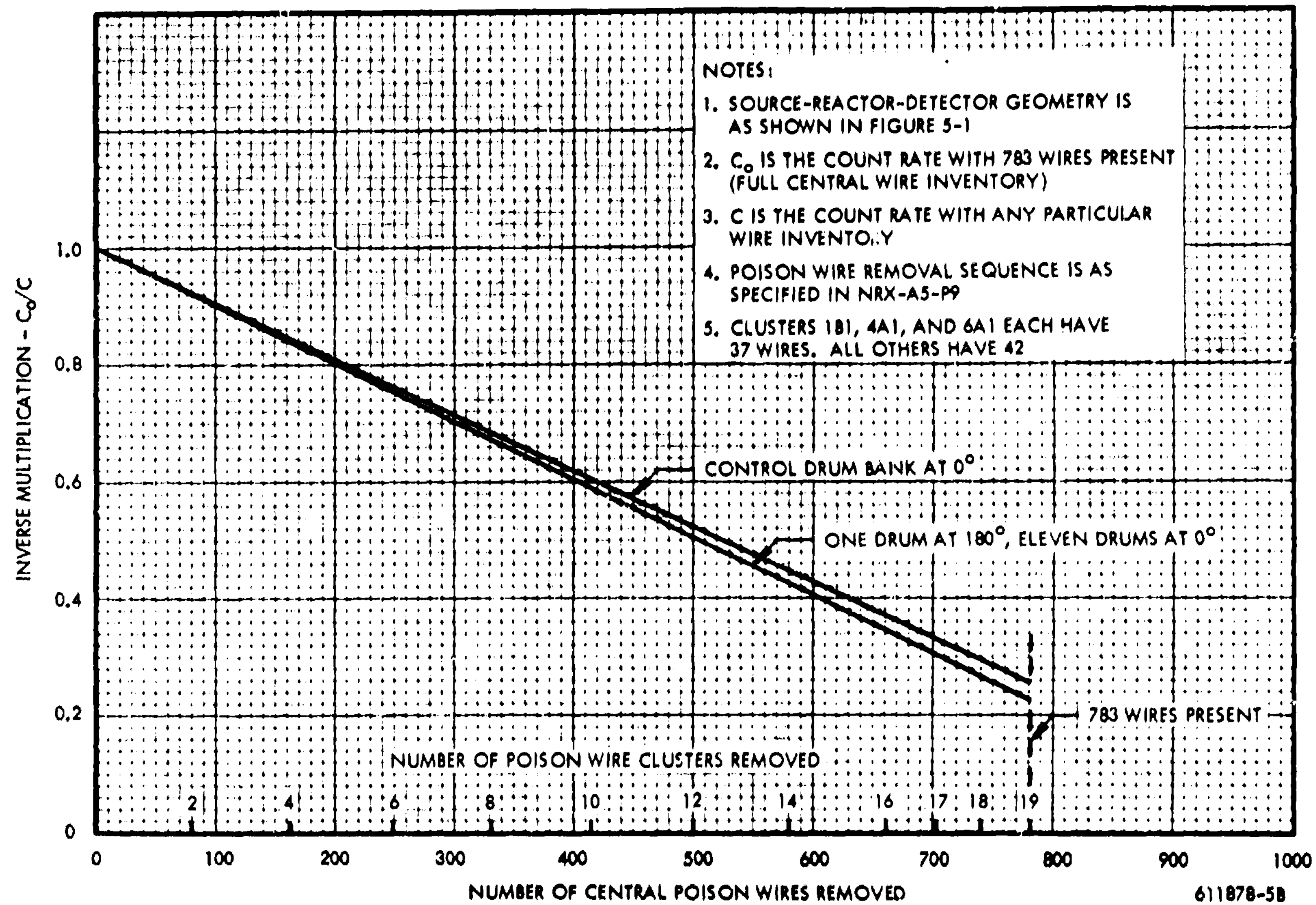

Figure 5-3. Predicted Inverse Multiplication for NRX-A6 Central Poison Wire Removal

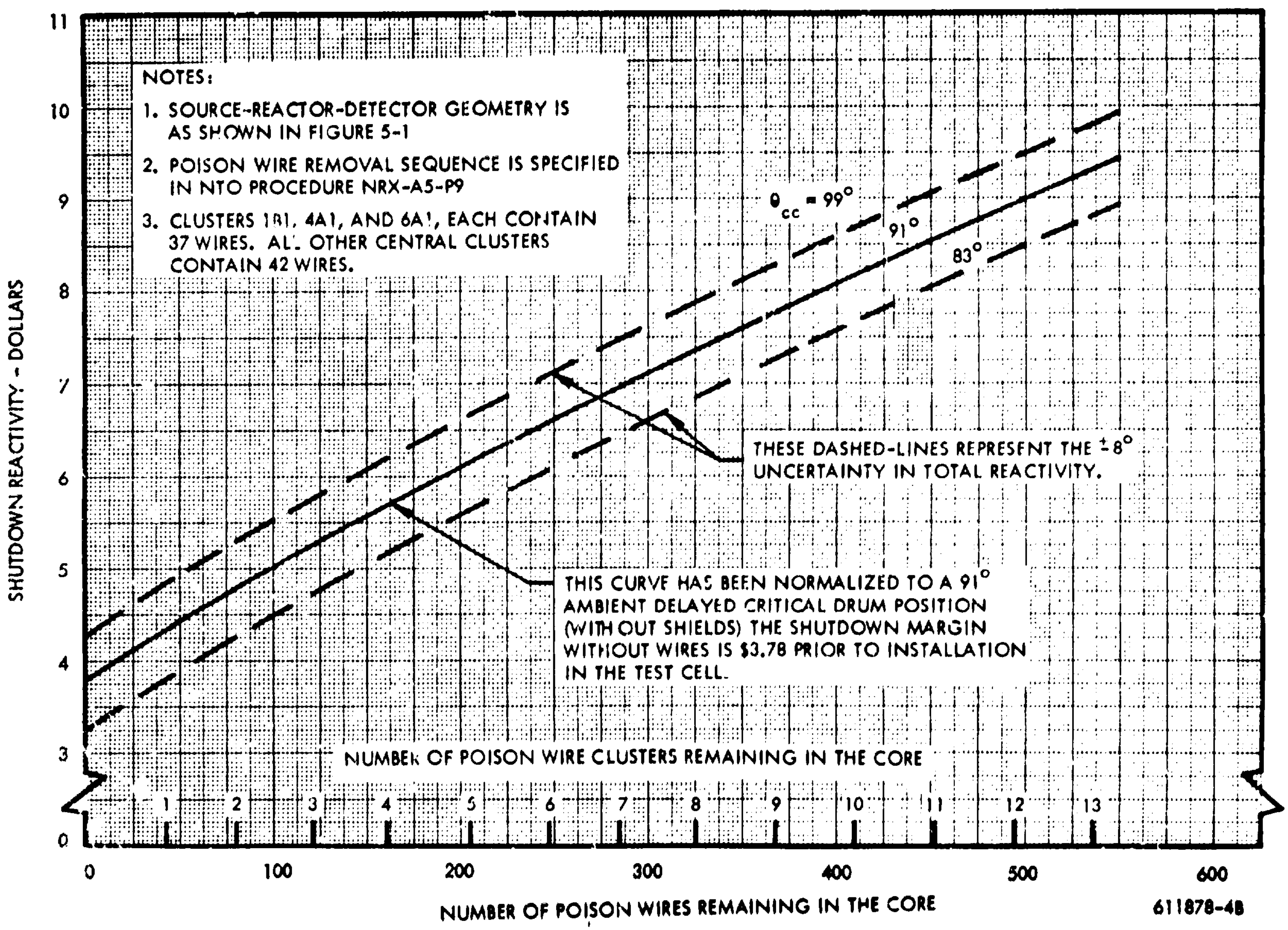

Figure 5-4 Predicted Variation in Shutdown Margin During NRX-A6 Central Poison Wire Removal

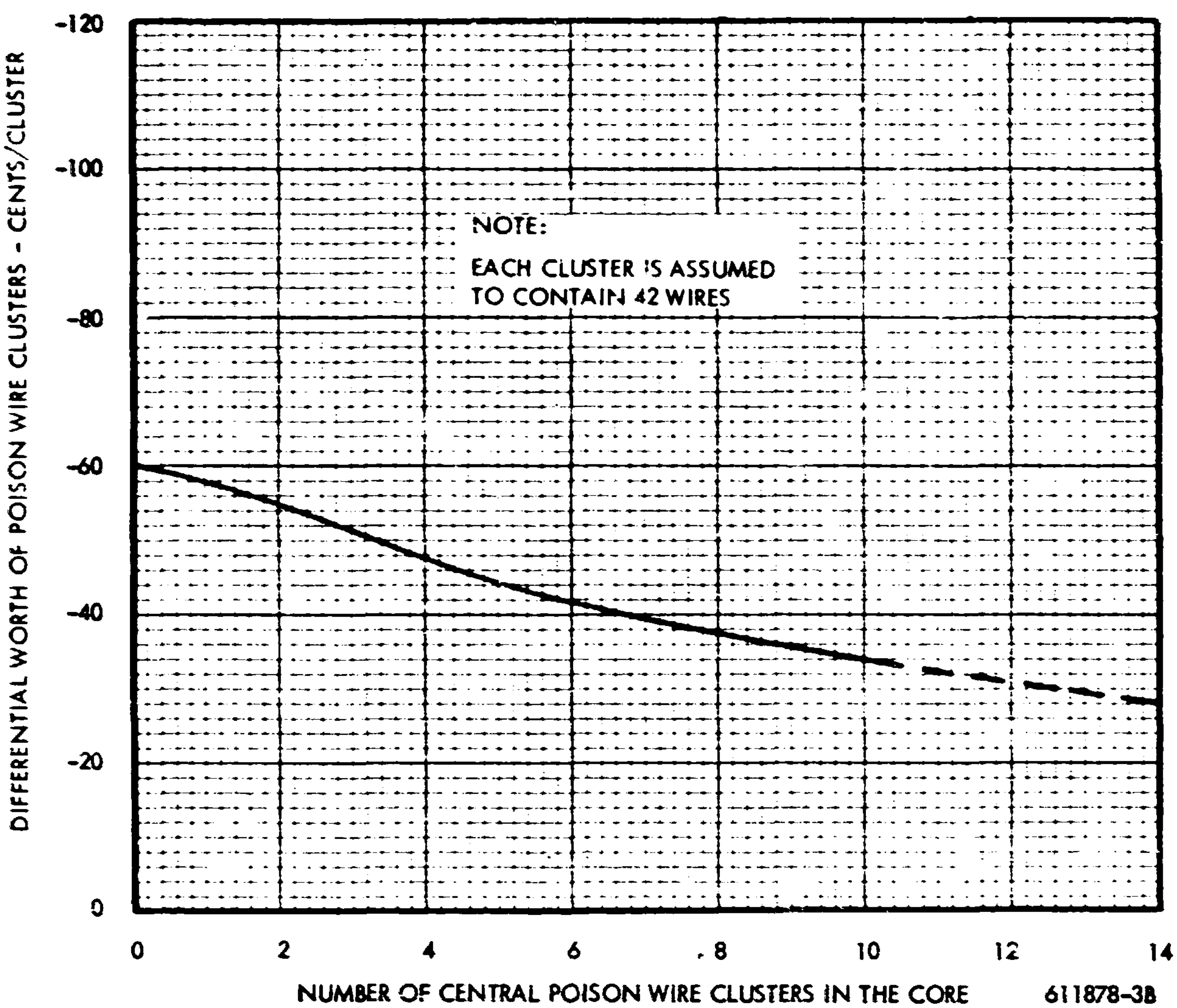

Figure 5-5. NRX-A6 Differential Worth of Poison Wire Clusters

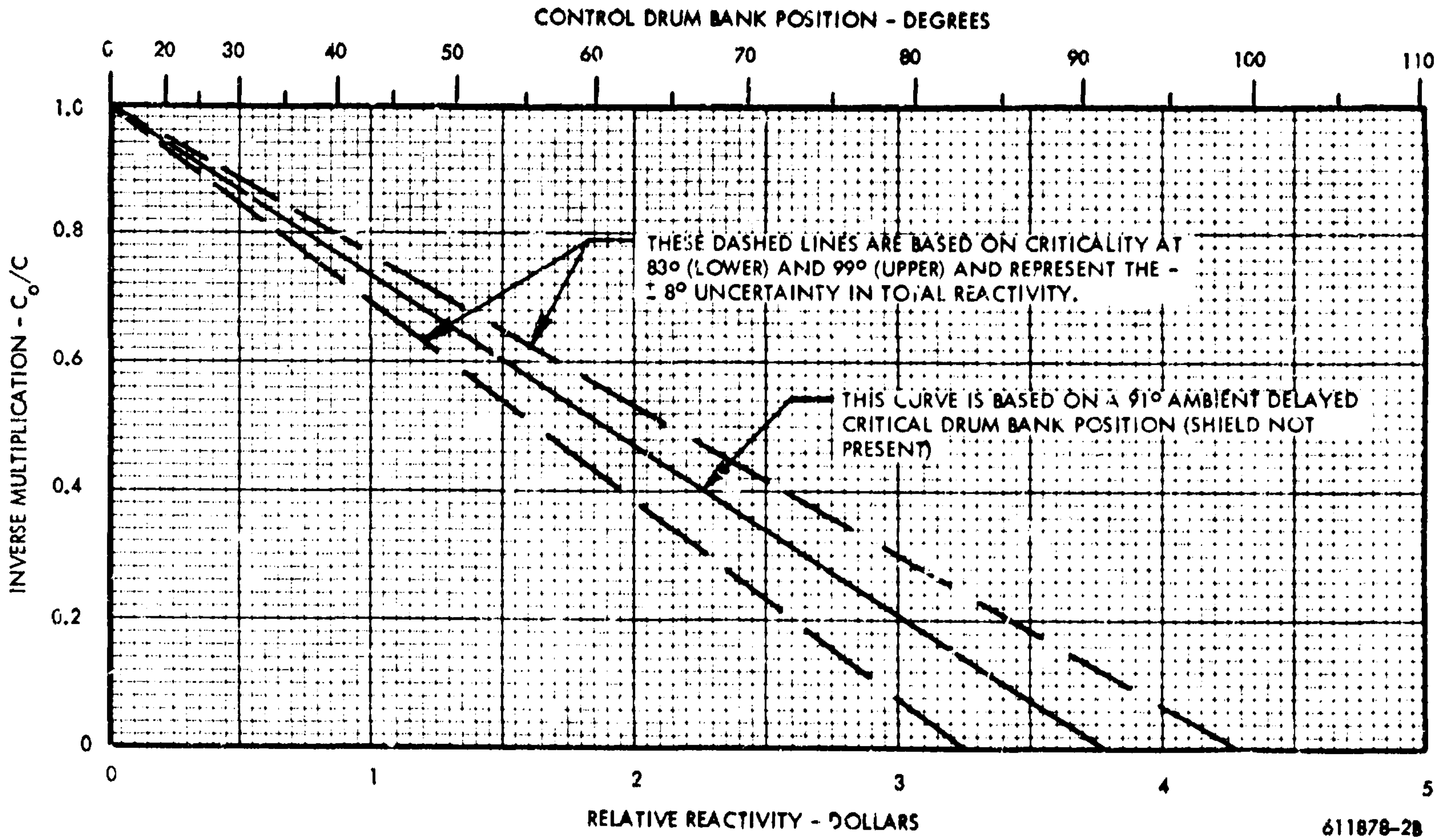

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Figure 5-6. Predicted Inverse Multiplication for Initial Criticality of NRX-A6 without Poison Wires and without Facility Shield

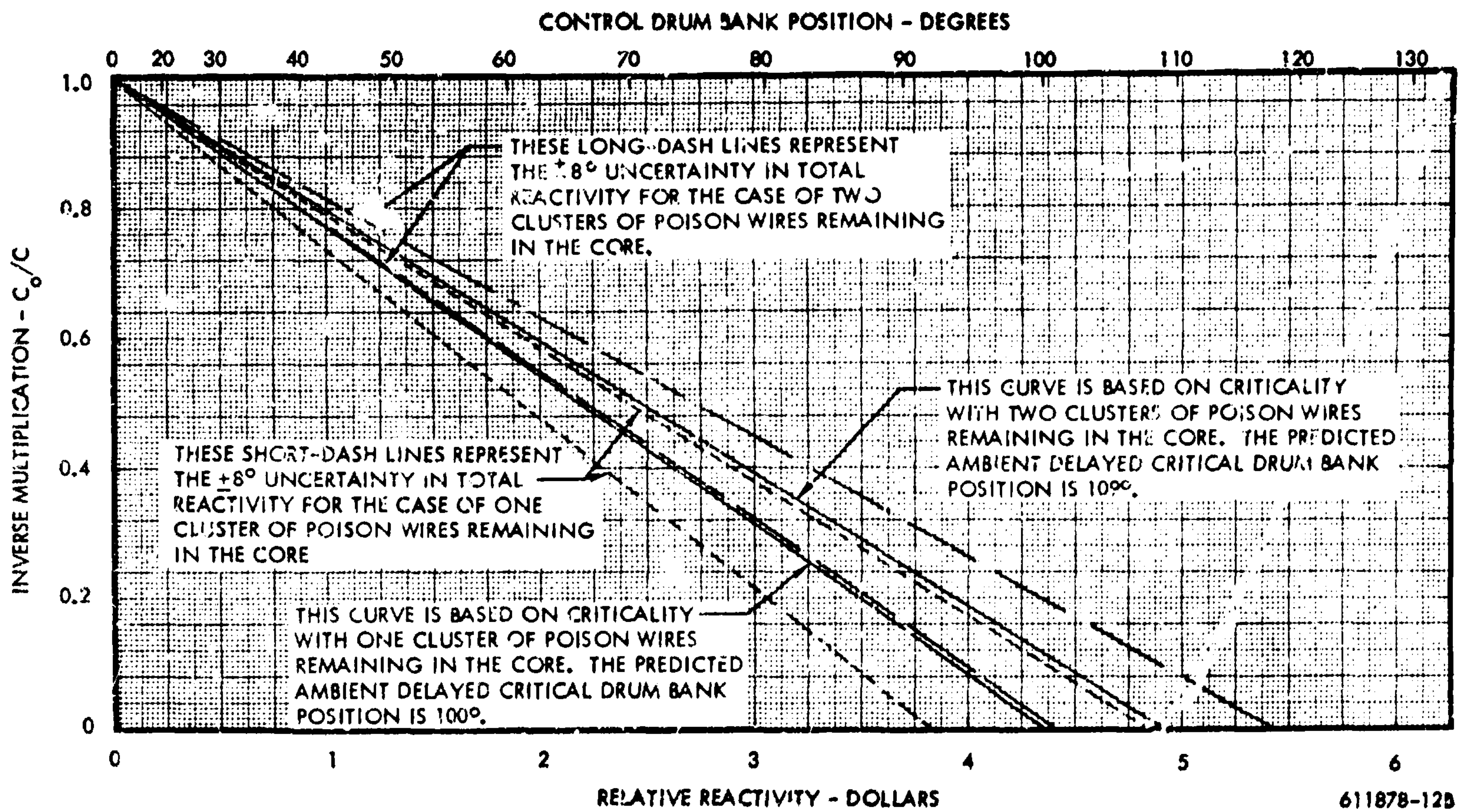

Figure 5-7. Predicted Inverse Multiplication for Initial Criticality of NRX-A6 with One and Two Clusters of Poison Wires Remaining in the Core and Facility Shield not Present

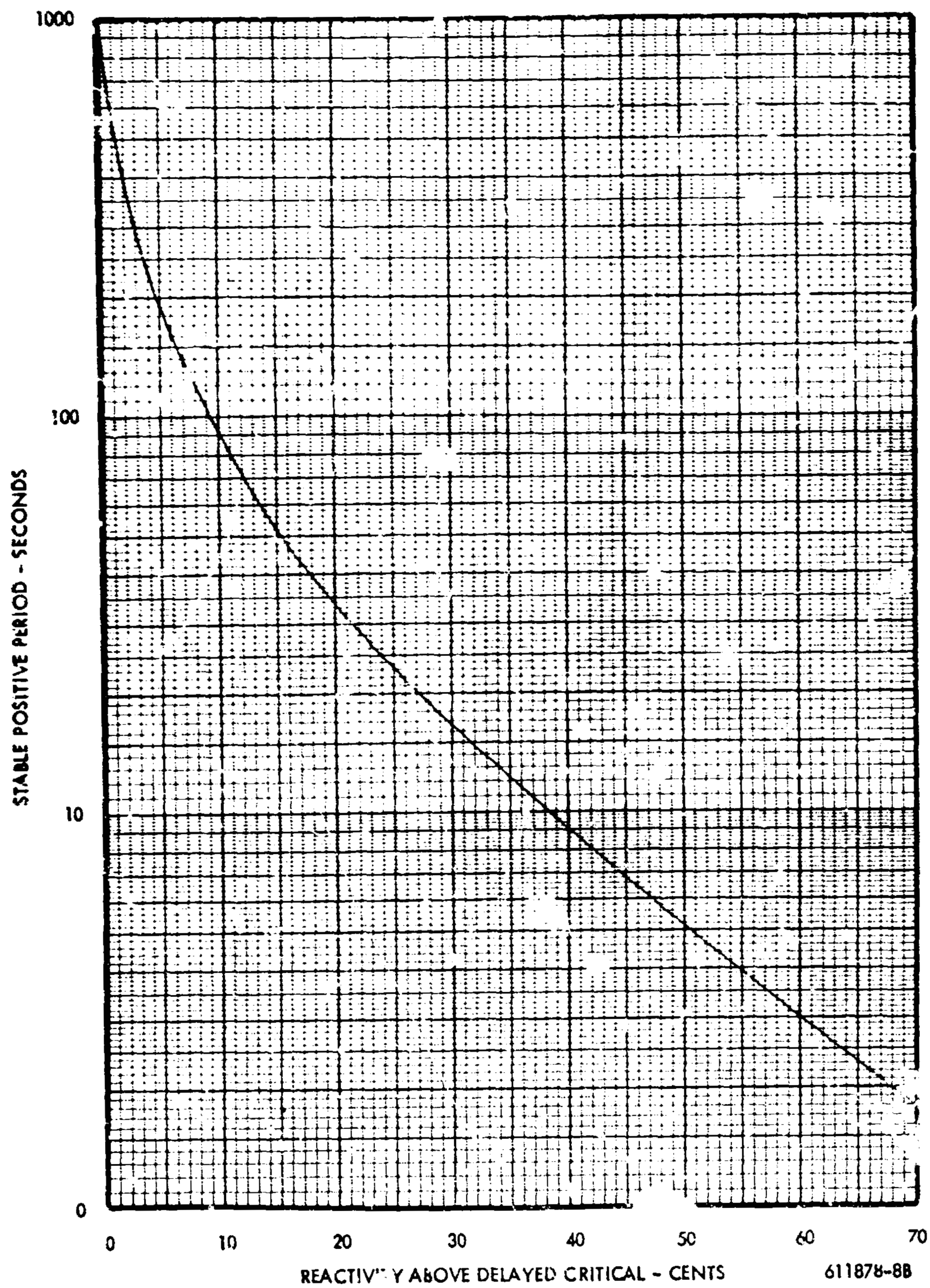

Figure 5-8. Variation of Stable Positive Period with Reactivity above Delayed Critical

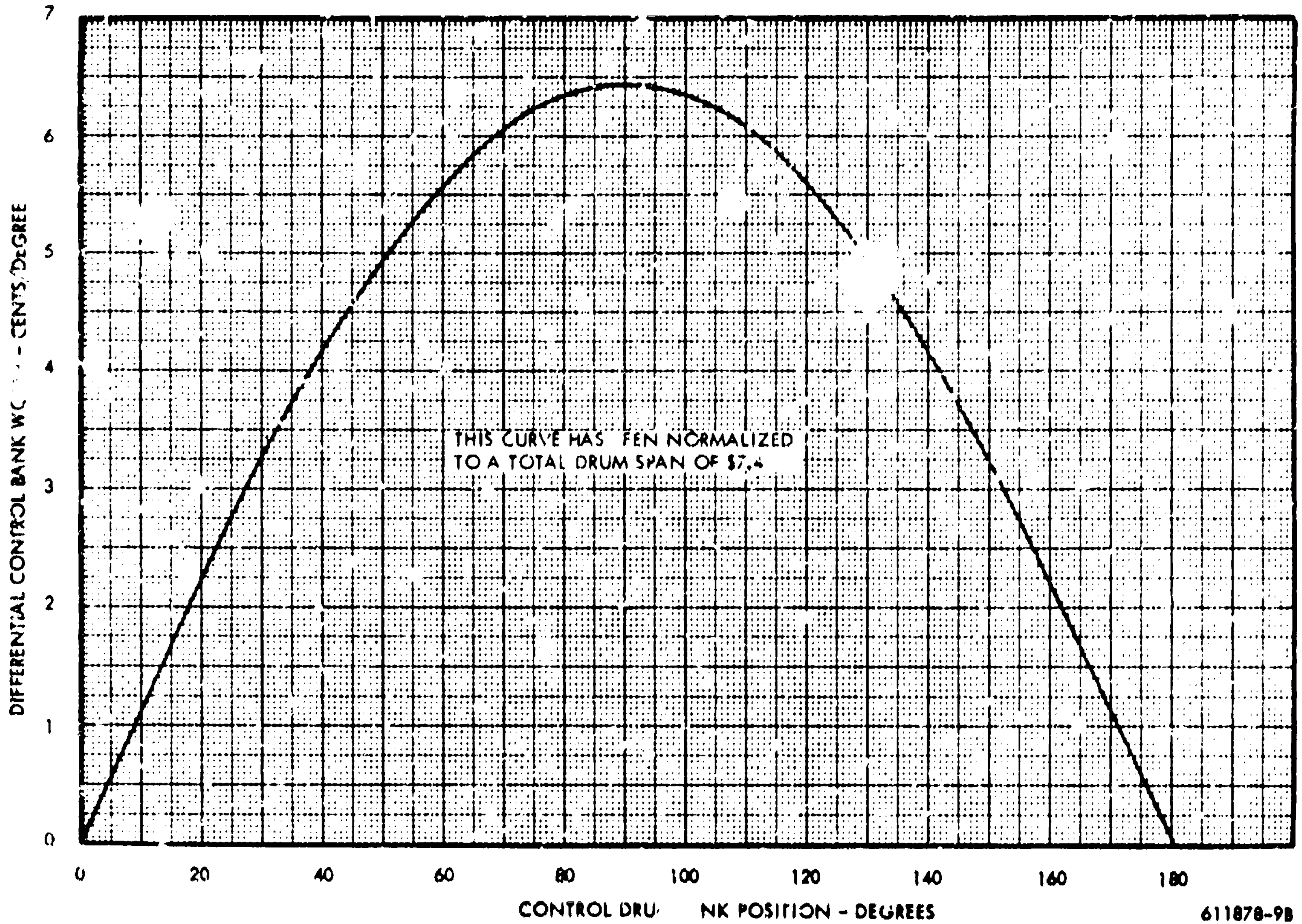

Figure 5-9. NRX-A6 Differential Control Drum Bank Worth

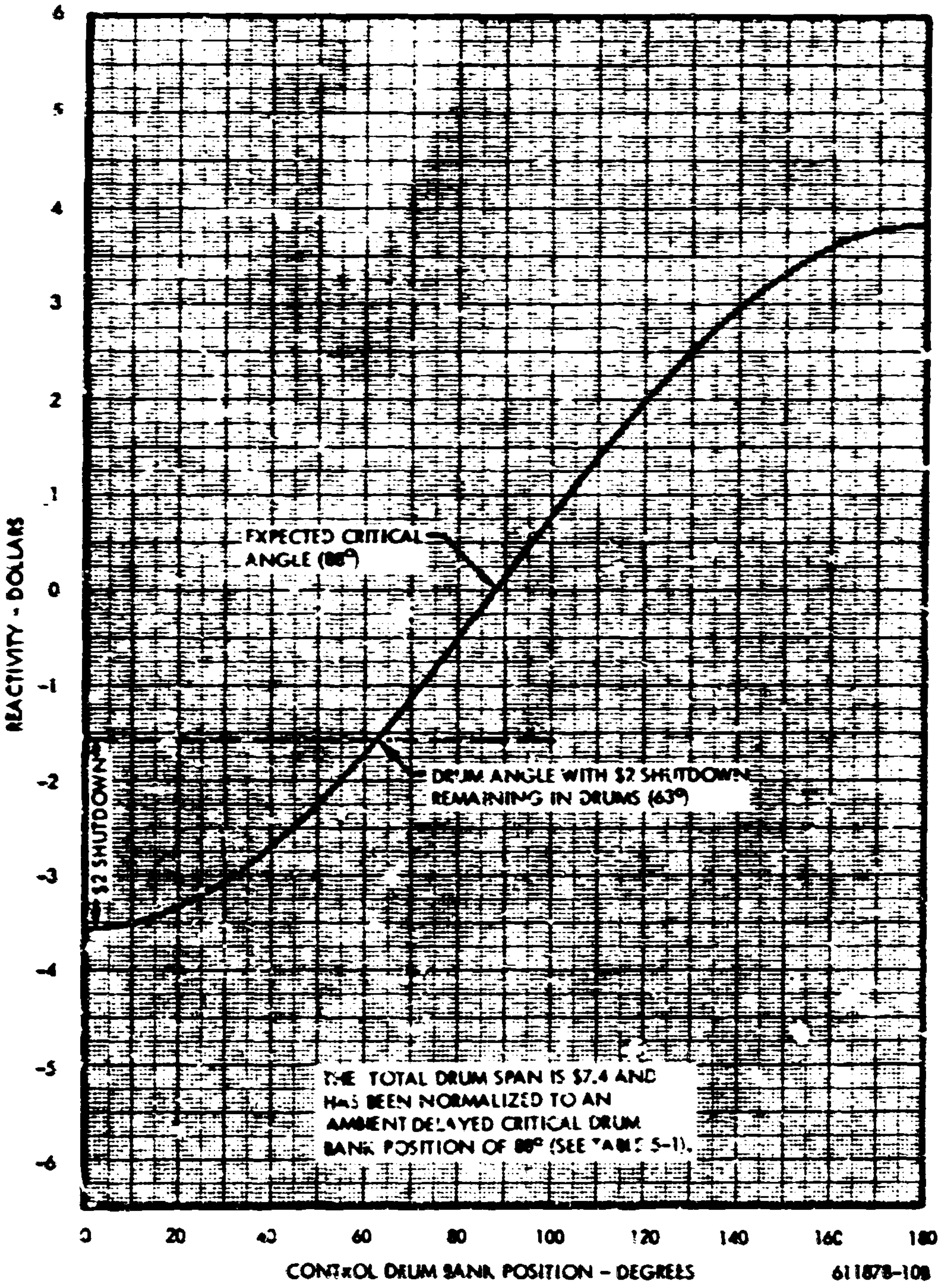

Figure 5-10. NRX-A6 Integral Control Drum Bank Worth - Variation of Shutdown Reactivity with Control Drum Bank Position

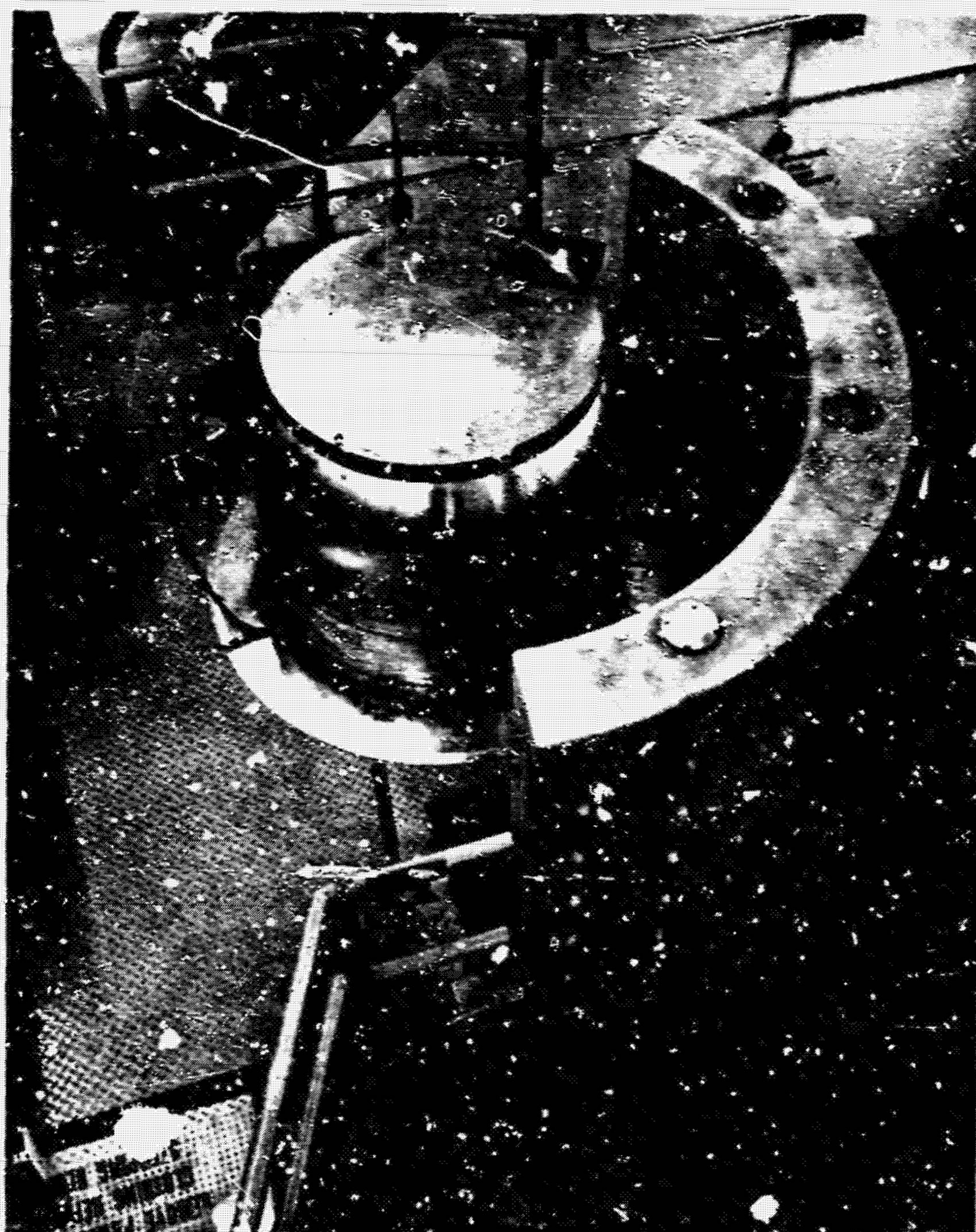

Figure 5-11. PAX Reactor with PRMS

6.0 FLOW TESTS

6.1 Ambient Nitrogen Flow Test

6.1.1 Objectives

The major objectives of the ambient gaseous nitrogen flow test are to provide assurance that the pressure instrumentation is ready for subsequent testing; to demonstrate the structural integrity of the redesigned reflector and lateral support system; and to provide base-point data for possible post-power test comparisons.

6.1.2 Profile Description

Prior to initiating flow the reactor will be brought to a nominal power of one kilowatt. Power will be maintained at this level throughout the test and for sixty (60) seconds after termination of coolant flow when the reactor will be scrammed. Stable drum position data will be obtained at each hold.

The flow of GN_2 will be increased on approximately a 4 lb/sec^2 ramp to 50 lb/sec and held for 10 seconds, them ramped at the same rate to 100 lb/sec and held for 20 seconds; and finally, the run shall be ended by shutting-off the flow. The flow profile is shown in figure 6-1.

6.1.3 Test Prediction

The test prediction figures are summarized in table 6-1. The reactor plenum pressures and component pressure drops are shown as a function of flow rate to simplify post test comparison. The calculations assume a 540°R temperature for the reactor and the nitrogen gas at the nozzle manifold. The predicted drum bank rotation from the delayed critical position (assumed to be 88 degrees) is 0.6 degree inward at 50 lb/sec flow and 1.2 degrees inward at 100 lb/sec flow.

6.2 Liquid Nitrogen Flow Test

6.2.1 Objectives

The objective of the liquid nitrogen flow test is to provide a low temperature stimulus to the reactor temperature transducers.

6.2.2 Profile Description

The test will be performed at zero power with the control drums locked. A flow rate of 10 lb/sec of liquid nitrogen will be established and maintained until a measurable decrease in core station 1 and/or tie rod temperature is observed. At this time the flow will be terminated.

6.2.3 Predictions

Reactor prediction data are not presented for this test because its only objective is to check the operation of the reactor temperature instruments.

TABLE 6-1

NRX-A6 AMBIENT NITROGEN FLOW TEST PREDICTION FIGURES

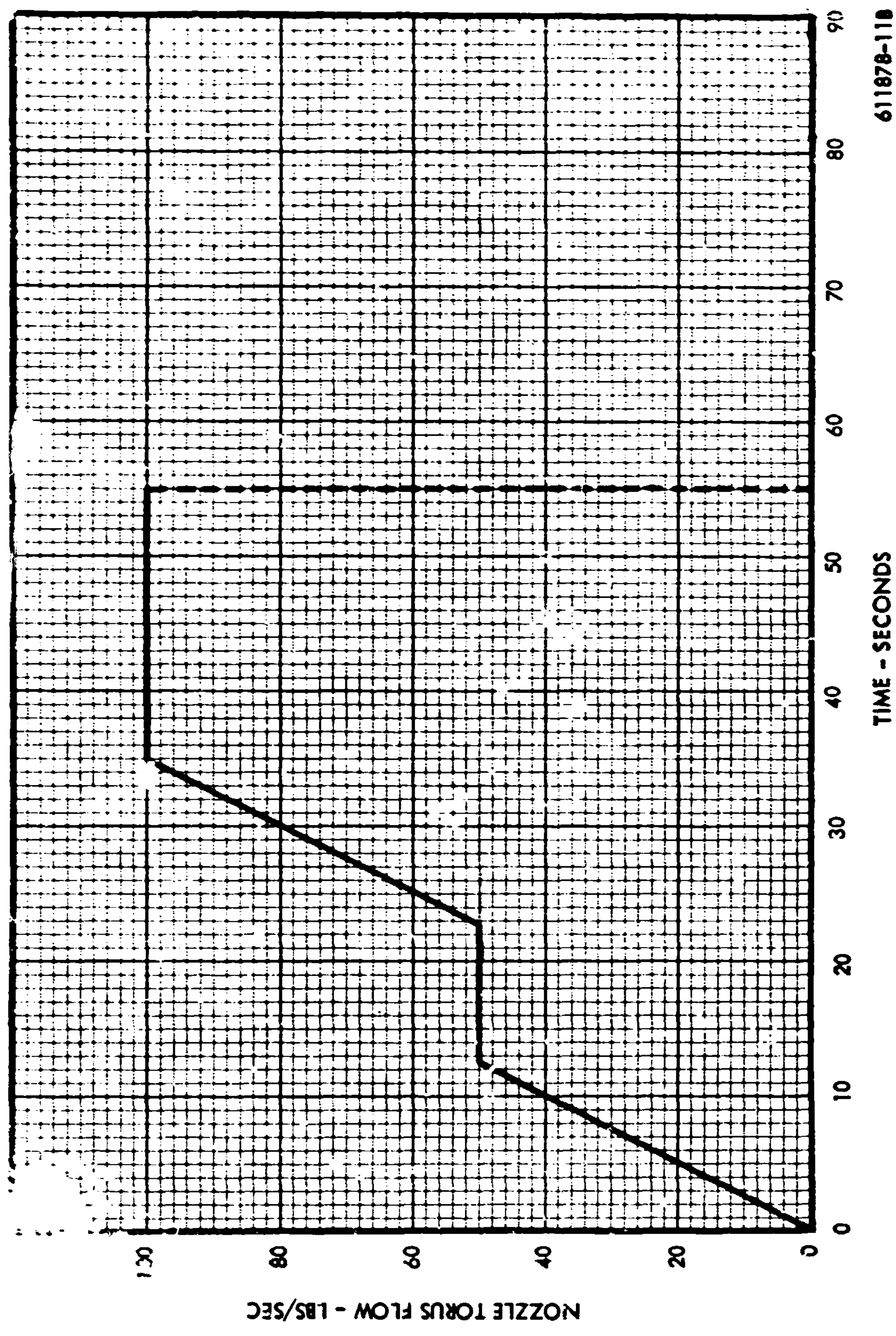

Figure 6-1. NRX-A6 Ambient Nitrogen Flow Test: Flow Rate

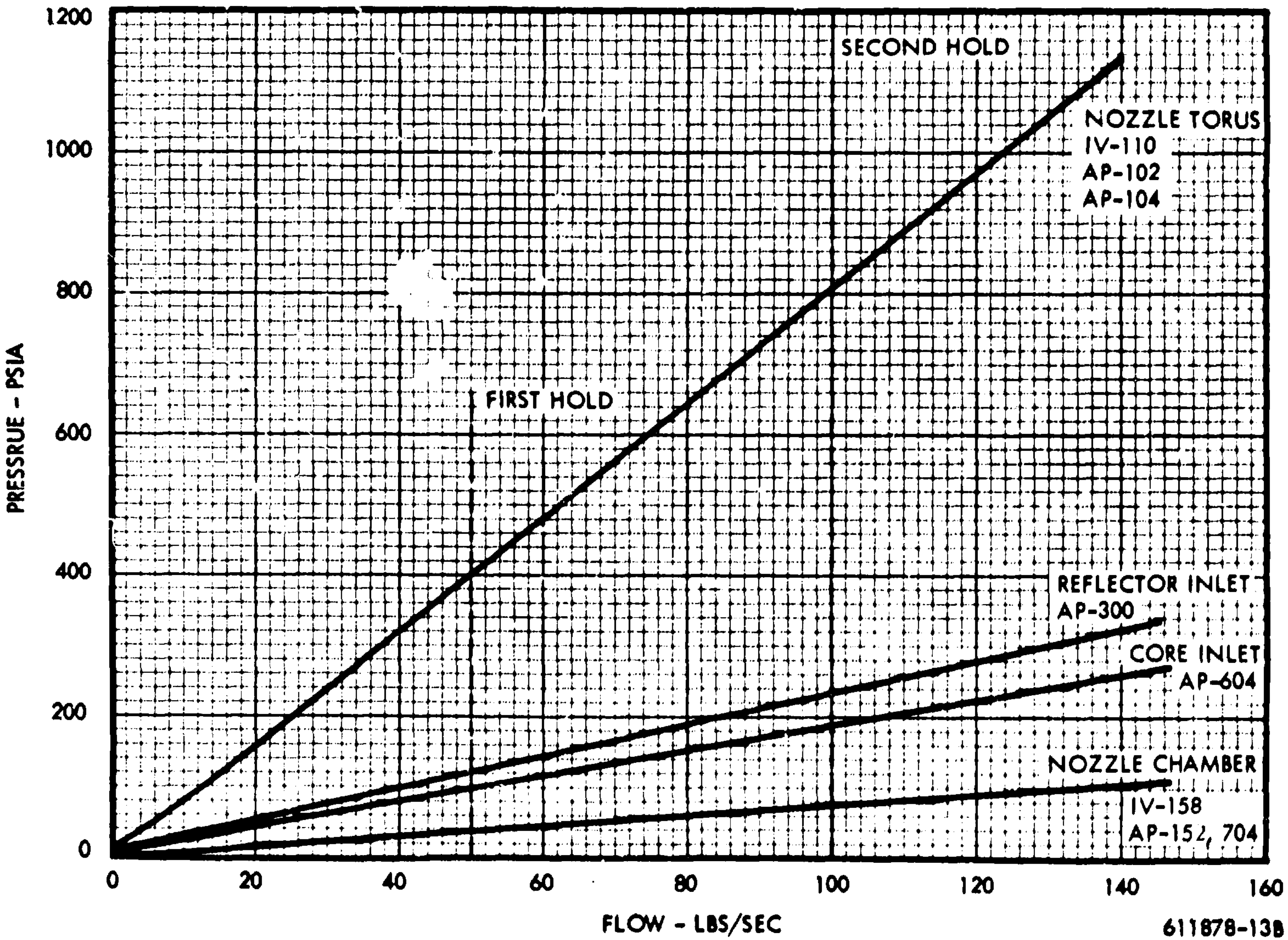

Figure 6-2. NRX-A6 Ambient Nitrogen Flow Test : Plenum Pressures

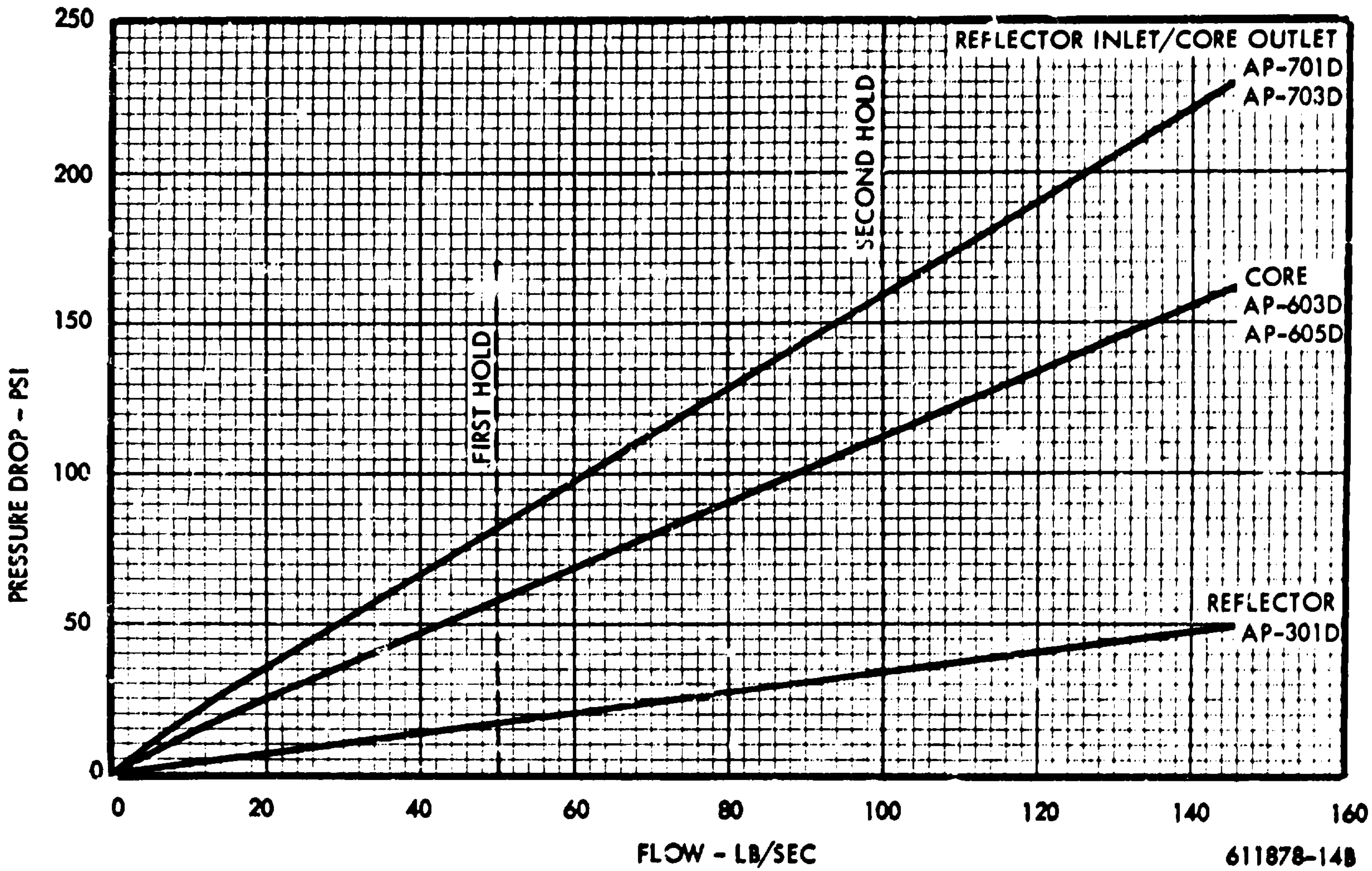

Figure 6-3. NRX-A6 Ambient Nitrogen Flow Test: Component Pressure Drops

7.0 REACTOR ENDURANCE TEST

7.1 Objectives

Endurance at rated conditions is the prime operational objective. The reactor will be operated at rated conditions for a time of 60 minutes or until a predetermined* loss of reactivity has occurred. A complete list of the experimental test objectives appears in the "NRX-A6 Test Specification[1]", Section I. B. 2.

7.2 Profile Description

The description of the reactor endurance test profile is divided into two parts - the preoperational phase and the power run.

During the preoperational phase, the reactor and facility are prepared for the power run. Only the more significant events are described in this section. The Control Room Operating Procedure, the detailed step-by-step description of both the preoperational phase and the power run, will be issued by NTO before the power run. The major preoperational events will be performed in the following sequence:

1) The following cryogenic lines will be chilled:

   (a) The main propellant line through H-101 and LF-111, the mixing chamber line to K-6, the high pressure dewar line to X-3, and the liquid nitrogen system to N-30. These pipes and valves are shown in figures 2-3 and 4-13.

2) An ambient hydrogen purge of 3 lb/sec through G-3 will be established.

3) The reactor power will be increased to 1 MW. (At this power the reactor core is heating up at approximately 1°R/sec. The time interval before initiation of the power run should not exceed 90 seconds, otherwise the initial outer reflector temperature limit of 540°R may be exceeded.)

The power run is initiated by discontinuing the 3 lb/sec ambient hydrogen purge flow and simultaneously starting the programmers. This is zero time in the prediction. The following parameters are programmed:

---

*The reactor endurance limit will be specified prior to the test.

(a) Nozzle chamber temperature

(b) Reactor power

(c) Liquid hydrogen flow rate at the LF-10 venturi

(d) L-111 valve position

(e) L-11 valve position

(f) Dewar 3 pressure

The first three are the primary parameters used to control the reactor during the power test. The two valve position demands, L-111 and L-11, are used to control reactor flow while the pump is in RPM control during the initial part of startup until L-111 is closed. The flow controller automatically takes over when the flow demand exceeds measured flow at LF-10. The dewar 3 pressure demand controls the pressure of the high pressure dewar which is used to provide the required emergency cooling flow if required at any time during startup, the endurance hold, and shutdown.

The reactor control parameters for the ramp to the 2000°R hold are neutronic power and flow rate (L-111 and L-11 valves control flow prior to flow loop closure); nozzle chamber temperature is not used for control during this ramp. However, the power and flow profiles are designed to produce a nominal 50°R/sec ramp in chamber temperature.

The following tests will be performed during the 2000°R chamber temperature hold:

a) Thermal power calibration.

b) Evaluation of test data to verify that the test assembly and facility are performing properly.

c) Limiter checks, response measurements, and other control tests. These tests are defined in Reference 1.

An estimated 3 to 5 minutes will be required to accomplish these tests during the 2000°R hold.

The ramp from the 2000°R hold to rated conditions will be performed in the temperature control mode at 50°R/sec (chamber temperature and flow rate are the primary control parameters). A 30 second duration intermediate hold will be programmed at 3700°R chamber temperature for the primary purpose of thermal stabilization and therefore to minimize stresses in key components.

The hold at design conditions (4090°R chamber temperature, 71.3 lb/sec flow rate, and 1120 MW power) will be maintained for a time of 60 minutes or until a predetermined reactivity loss has occurred. The Test Specification[1] requires that at least one limiter either power or core station 26 temperature be active to continue the hold. The objectives and operation of the limiters are described in Section 7.6.

The shutdown will be performed in flow rate and temperature control. Flow rate will be programmed at -0.9 lb/sec^2 to 42.5 lb/sec, and temperature will be programmed at 50°R/sec to 2500°R. At this time (32 seconds after start of shutdown) the following actions will be simultaneously performed:

a) Reactor scram

b) Automatic initiation of flow from dewar 3 (high pressure dewar).

The predictions for time after scram will be issued in a supplement since the high pressure dewar pressure profile and other design parameters have not been finalized.

7.3 Demand Profiles*

Figures 7-1 through 7-5 show the demand profiles of chamber temperature, log power, flow rate, L-111 valve position, and L-11 valve position for startup and shutdown. The dewar 3 pressure profile is shown in figure 9-1. These are to be used as the basis of the scaled profiles which will be inscribed on the program drums. Ten seconds of hold time are included in the profiles to permit sufficient reaction time to stop the drums at the holds. The dashed parts of the power and temperature demands indicate the intervals where the dashed parameter is not used for closed loop control.

The profiles consist of startup and shutdown in consecutive sequence. The programs are not normally reversed for shutdown. Reversing of the drums would only be done if an accident occurred during startup, provided this mode of shutdown was deemed best.

The demand profiles are further described below:

a) Chamber Temperature - Temperature control is utilized from the 2000°R hold to rated conditions, during the hold at rated condition, and for shutdown until reactor scram at 2500°R chamber temperature.

---

*This section utilizes the feedsystem schematic shown in figures 2-3 and 4-13.

b) Log Power - Log power is used in closed loop control for the ramp to the 2000°R hold. The power profile is designed to produce a nominal 50°R/sec ramp starting at 9 seconds after initiation of run. For the first 9 seconds, the power is increased on a 2.5 second period from 1 MW.

c) Flow Rate - The demand flow rate at the L-11 control valve is shown. During the initial part of startup the pump is in RPM control and the flow rate is determined by the positions of L-111 and L-11. The pump is controlled by the flow rate profile when the demand exceeds the measured flow at about 32 seconds after initiation of startup. The flow rate at the nozzle torus is less than the demand flow by the amount of flow lag in the feed-system and any leakage to the K (Low pressure liquid hydrogen system for cooldown) and the X (high pressure dewar system for emergency cooling) systems.

d) L-111 and L-11 Valve Positions - Prior to initiation of reactor flow, the pump and cryogenic lines to L-11 are chilled with LH_2 flow from the pump run tanks. During this operation, valve L-11 is closed and flow is vented through valve L-111 which is open to approximately sixty-two percent. The turbine gas flow is provided at approximately 150 psia from pressure control of valve H-53. This valve is automatically closed when pump bootstrap conditions raise pressure above 250 psia. The flow controller is biased to provide an rpm demand signal such that the pump discharge pressure is approximately 200 psia. To initiate reactor flow, L-11 is programmed open while L-111 is programmed closed and the reactor flow demand program is started. Thus, flow is altered from the vent line to the reactor. When the demanded LF-1C flow exceeds the measured flow, the flow controller overrides its initial bias and actively maintains the flow demand. The bias is then removed and its removal has no effect on the rpm demand from the flow controller. The startup is then continued to the 2000°R hold in the power and flow control modes.

7.4 Digital and Analog Predictions

The prediction figures for the startup and shutdown are listed in table 7-1. The data channel names of all parameters that are recorded on the Sanborn recorders are shown on the prediction figures. The steady state predictions for the 2000, 3700, and 4090°R chamber temperature holds are given in table 7-2 for facility parameters and in table 7-3 for reactor parameters. The facility predictions were computed with the analog computer and the reactor predictions were computed with the TNT (Thermal and Nuclear Transient) digital code. The following assumptions were made for the digital calculations:

a) The initial reactor temperatures are uniformly 540°R.

b) The initial power is 1 MW with an equilibrium precursor concentration.

c) The power is increased on a 2.5 second period during the first 9 seconds.

d) The facility can be programmed to achieve the flow rate shown in figure 7-3 at the L-11 control valve.

e) The piping to L-11 is prechilled, and the piping from L-11 to the nozzle torus is not prechilled. A digital flow lag calculation was made to compute the nozzle torus flow and temperature shown in figures 7-11 and 7-12.

f) The design core pressure drop is 135 psia.

g) The hold durations are 3 minutes at 2000°R chamber temperature and 30 seconds at 3700°R.

For the analog feedsystem predictions, the startup transients were begun 7 seconds into the profile because of limitations in analog computer resolution. This problem will be overcome and a revised set of predictions will be issued in a supplement to this report.

Prior to starting the profiles, the flow controller was biased to demand a 10000 rpm output of the turbine. L-11 was closed and L-111 was open. Approximately 36 lb/sec was bypassed out L-111. An ambient hydrogen purge flow of 3 lb/sec was established through G-3. The turbine was powered with gas from the tank farm by pressure control of H-53 with a 250 psi pressure demand. The L-11 and L-111 valve programs shown in figures 7-4 and 7-5 by solid lines were started 7 seconds later than that for the planned startup. The planned profiles are shown by dashed lines. The reactor nozzle torus temperature was decreased from 540°R to 40°R exponentially on a 5 second time constant. Flow through L-11 shuts off the ambient hydrogen flow. The flow controller overrode the rpm bias when LF-10 flow exceeded the flow demand. Approximately 30 seconds elapsed before pump discharge pressure rose sufficiently to force flow to the heat exchanger, thus, automatically closing H-53 and establishing closed loop pump bootstrap conditions.

A continuing effort is being made to determine L-II and L-III valve programs that will insure an exact 1.1 lb/sec^2 flow ramp on startup at L-II. The results of recent facility tests will be used in support of later simulation of the startup. Because of the present difficulty in obtaining analog startup prediction from time zero, the feedsystem results should be regarded as preliminary. The final feedsystem startup predictions will be issued in an addendum to this report.

7.5 Control Drum Predictions During High Power Hold

This section will be published in a supplement once the final core design data are available.

7.6 Control System Predictions

This section presents predictions for the scheduled control system tests. A step response of the temperature controller will be performed at the 2000°R hold on startup. The temperature and power limiters will be checked out during this hold also. These tests will not be performed exactly as described below, but the predictions are included as a general illustration of the performance of the control systems. The limiter test described below is for checkout at the 3700°R hold, however, this was later changed to the 2000°R hold. Predictions for checkout at the 2000°R hold are not presently available but will be issued in a supplement to this report. A description of the controls tests follows.

At the 2000°R hold, the reactor control mode will be changed from power to chamber temperature control. When temperature control is established, a negative step of 50°R will be inserted into the controller. The predicted response of measured chamber temperature is shown in figure 7-27 for the step-in and step-out in the temperature demand signal.

The temperature limiter limits power based on station 26 measured versus set point temperature. The limiters provide signals to the control drums only for measured values of their controlled parameters greater than their set points. During the ramp from 2000°R to 3700°R, the temperature limiter is set to limit chamber temperature at 3650°R. After limiting occurs, the power limiter set point is decreased so that it overrides the temperature limiter and decreases temperature to 3600°R. The power limiter and then the temperature limiter are reset to their values corresponding to design limits. Predicted power, chamber temperature, power limiter, and temperature limiter outputs are shown in figure 7-28.

Detailed descriptions of the temperature and power controllers and their respective limiters is contained in references 23 through 26. The following paragraph from reference 1 describes the objectives and operation of the limiters: Limiter circuits will be included in the control system to limit the measured values of log power and station 26 temperature when in temperature and power control modes. The limiters will function along with the neutronic scrams to prevent exceeding either the nozzle material temperature limit or a maximum Station 26 temperature of 350°R above rated T_{26} in the event of control drum runouts of any velocity at any time during the test. Each limiter circuit will have two (2) inputs, the measured parameter and the limit level setpoint. Whenever the measured parameter exceeds the limit level setpoint, the output of the limiter circuit will demand the control drums to move in the inward direction, so as to maintain the parameter near its limiting value. The power limiter is required only during holds at nominal rated conditions. Both the temperature and power limiter shall be capable of operation in order to begin a full power test. The limit level shall set at the following values:

Parameter	Setpoint
Log Nm.	1050% of rated power
T_{26}	90° below the T_{26} test parameter limit

TABLE 7-1

LIST OF NRX-A6 ENDURANCE TEST PREDICTION FIGURES

TABLE 7-1 (Continued)

TABLE 7-2

STEADY-STATE FACILITY DATA FOR HOLDS DURING STARTUP

Chamber Temperature (^{o}R)	2000	3700	4090
Flow Rate (lb/sec)	40.0	65.5	71.3
Turbine Inlet Pressure (psia)	100.0	288.0	355.0
Turbine Power Control Valve H-60 (% open)	12.5	21.0	22.5
Turbine Speed (rpm)	11250.0	21000.0	22250.0
Pump Flow Rate (lb/sec)	49.0	80.0	86.8
Pump Bypass Valve L-109 (% open)	18.0	18.0	18.1
Pump Bypass Valve Flow (lb/sec)	7.0	9.0	9.0
Heat Exchanger Flow (lb/sec)	2.0	5.5	6.5
Pump Discharge Pressure (psia)	345.0	780.0	900.0
Heat Exchanger Inlet Valves (% open)	4.5	13.0	17.0
Reactor Flow Rate (lb/sec)	40.0	65.5	71.3

NOTE: All facility data were computed with the NRX-A6 reactor and feedsystem common analog model.

TABLE 7-3

STEADY STATE REACTOR DATA FOR HOLDS DURING STARTUP

Nozzle Chamber Temperature, °R		2000	3700	4090
Thermal Power, MW		290	918	1120
Flow Rate, lb/sec		40	65.5	71.3
Control Drum Position(2), degrees		74	87	90
Nozzle Torus:	T	43	49	50
	P	328	770	893
Reflector Inlet:	T	71	138	154
	P	285	647	743
Reflector Outlet:	T	110	208	231
	P	277	624	716
Shield Dome:	T	111	209	233
	P	275	620	711
Core Inlet:	T	117	217	242
	P	273	615	706
Core Exit:	T fuel exit	2127	3940	4339
	T tie rod	419	591	645
	P	219	497	571
Unfueled Temperatures:				
Station 20		1349	2782	3189
Station 26		1594	3299	3760
Component Pressure Drops (psi):				
Reflector		8.8	23.2	27.0
Shield and Support Plate		3.8	9.0	10.4
Core		53.5	117.8	135.0
Reflector Inlet to Core Exit		66.1	150.1	172.4

Notes: (1) All T's in °R, and P's in psia.

(2) Based on an ambient delayed critical drum bank position of 88°. All molybdenum coating loss (approximately 8 degrees) is assumed to occur by the end of the first hold.

(3) All reactor data were computed by the TNT digital computer program.

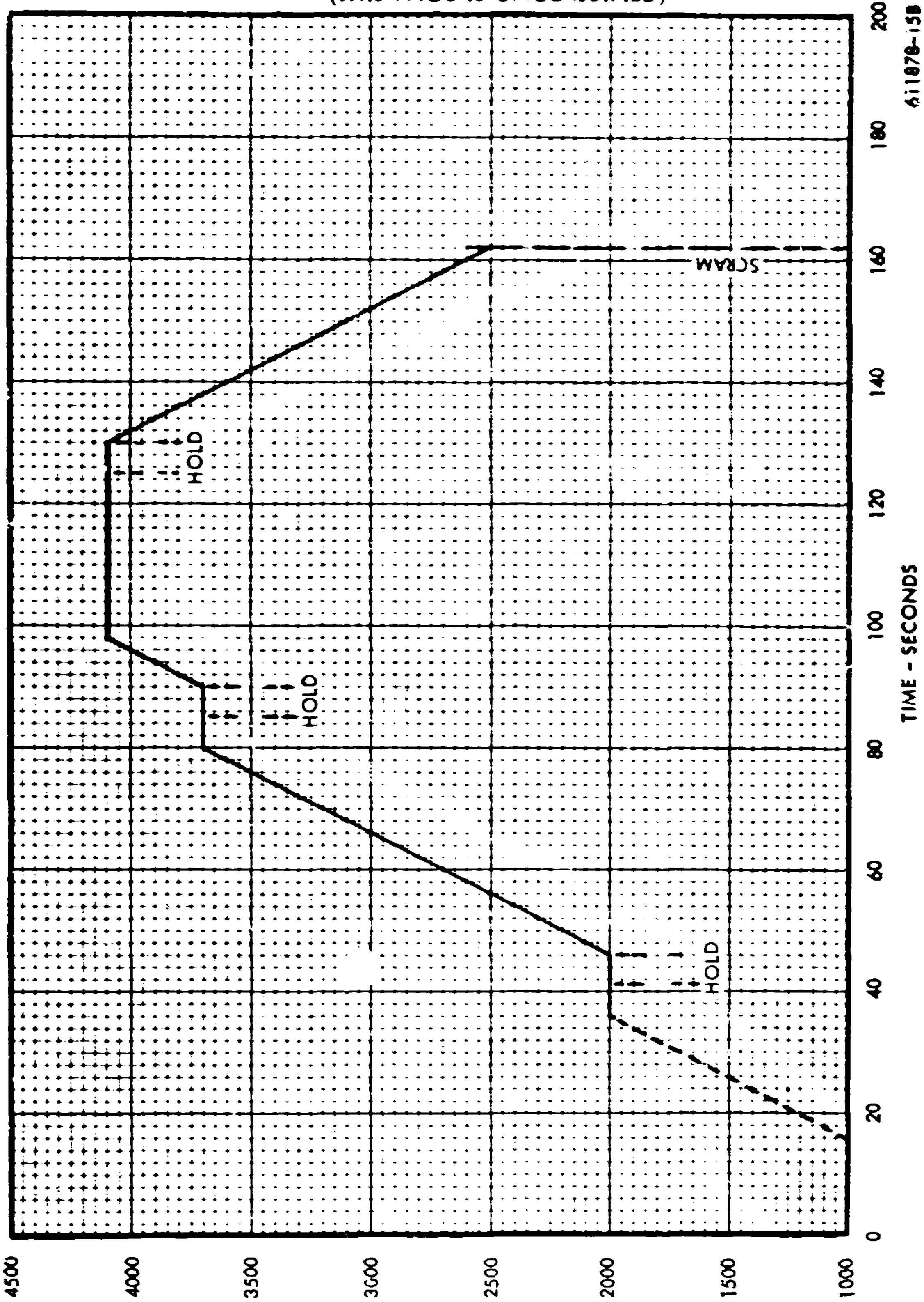

Figure 7-1. Demand Nozzle Chamber Temperature

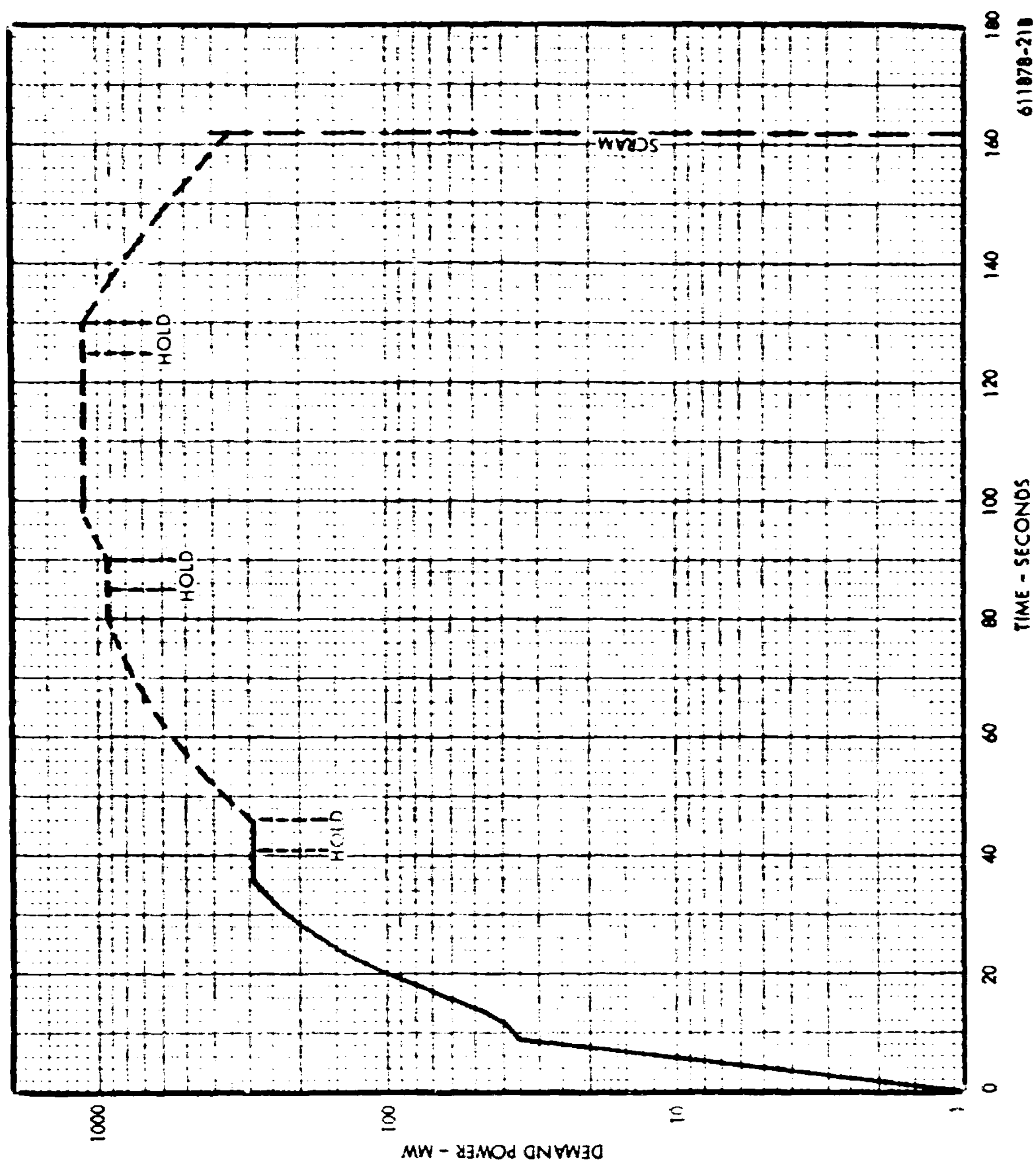

Figure 7-2. Demand Power

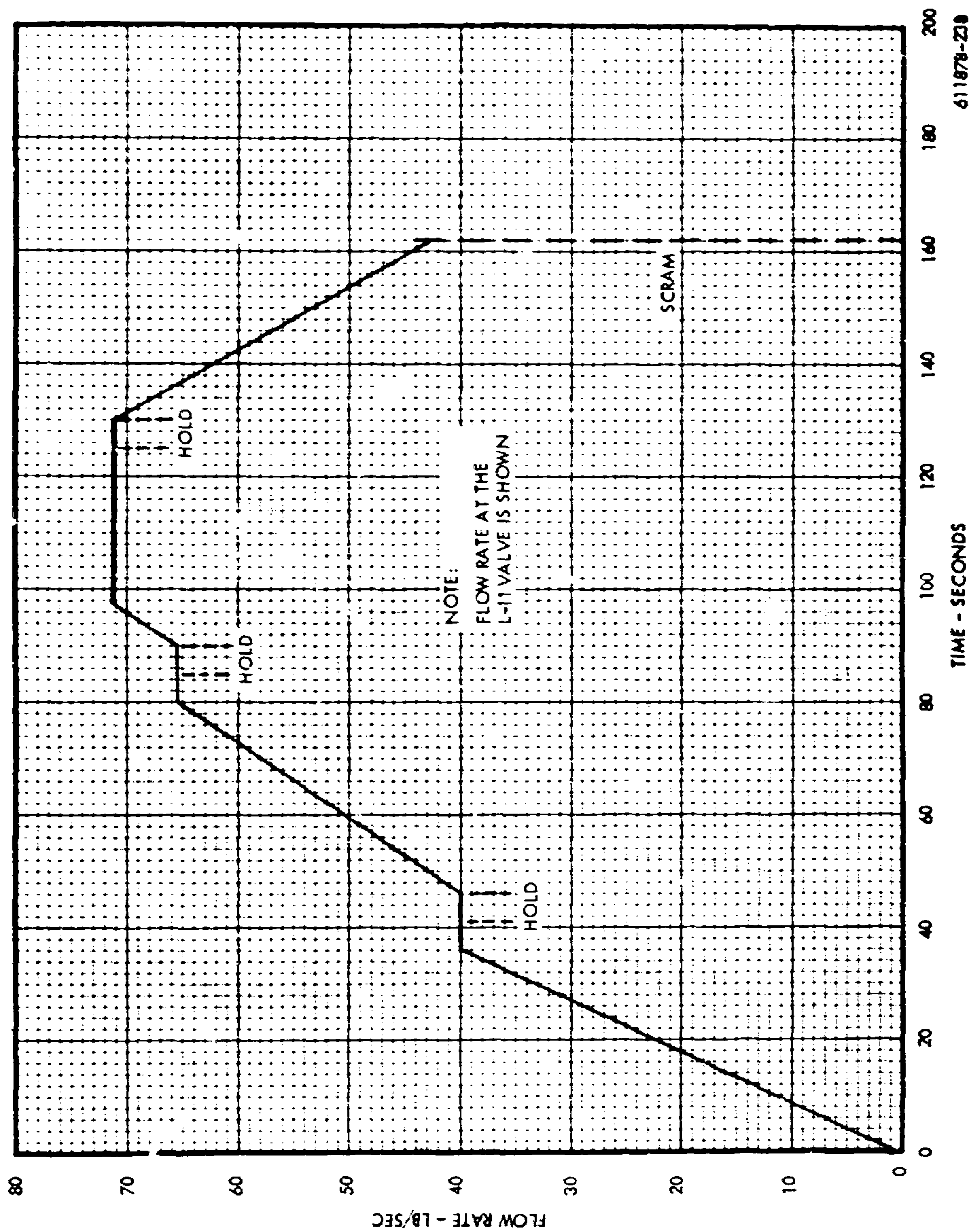

Figure 7-3. Demand Liquid Hydrogen Flow Rate

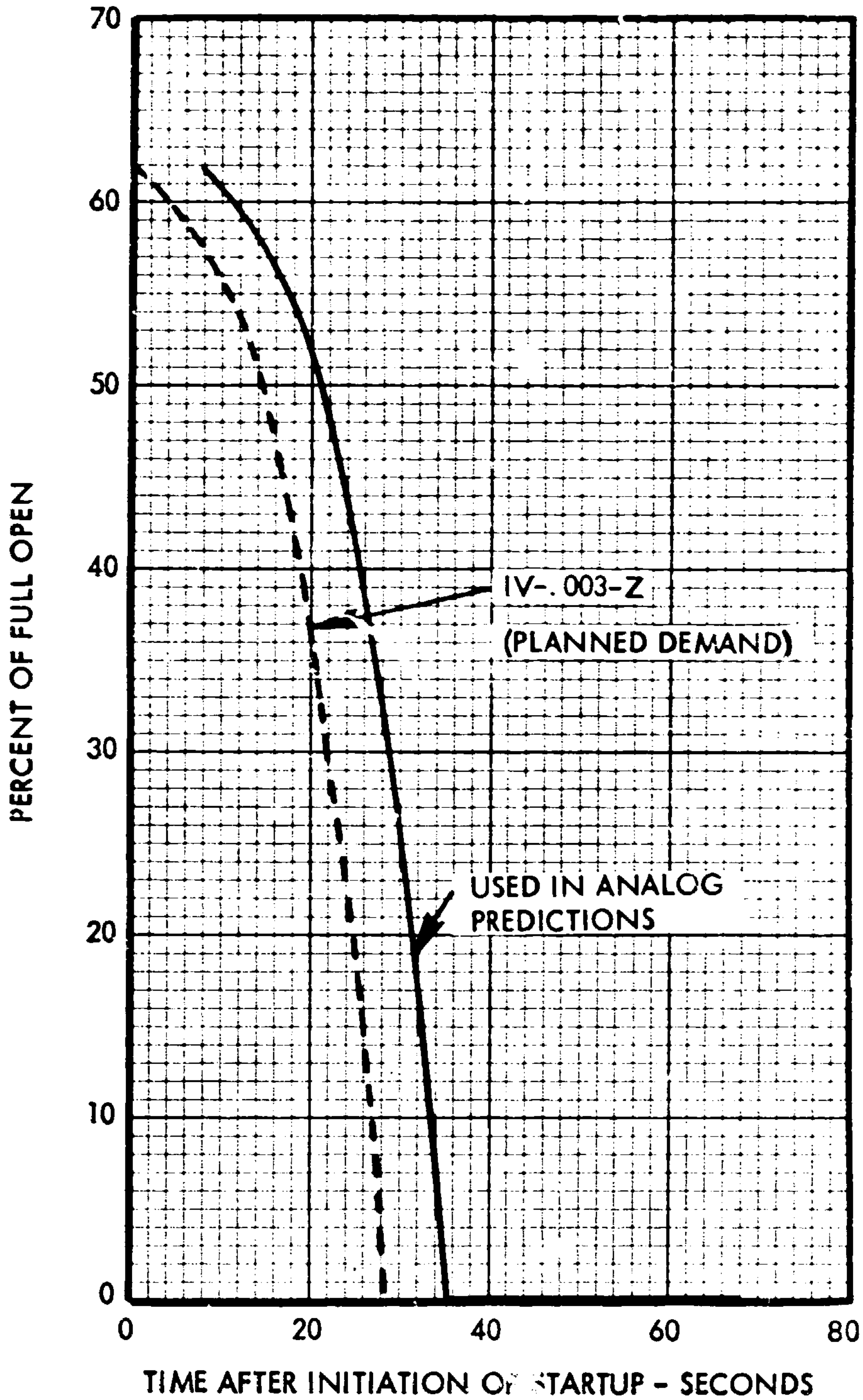

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Figure 7-4. L-111 Demand

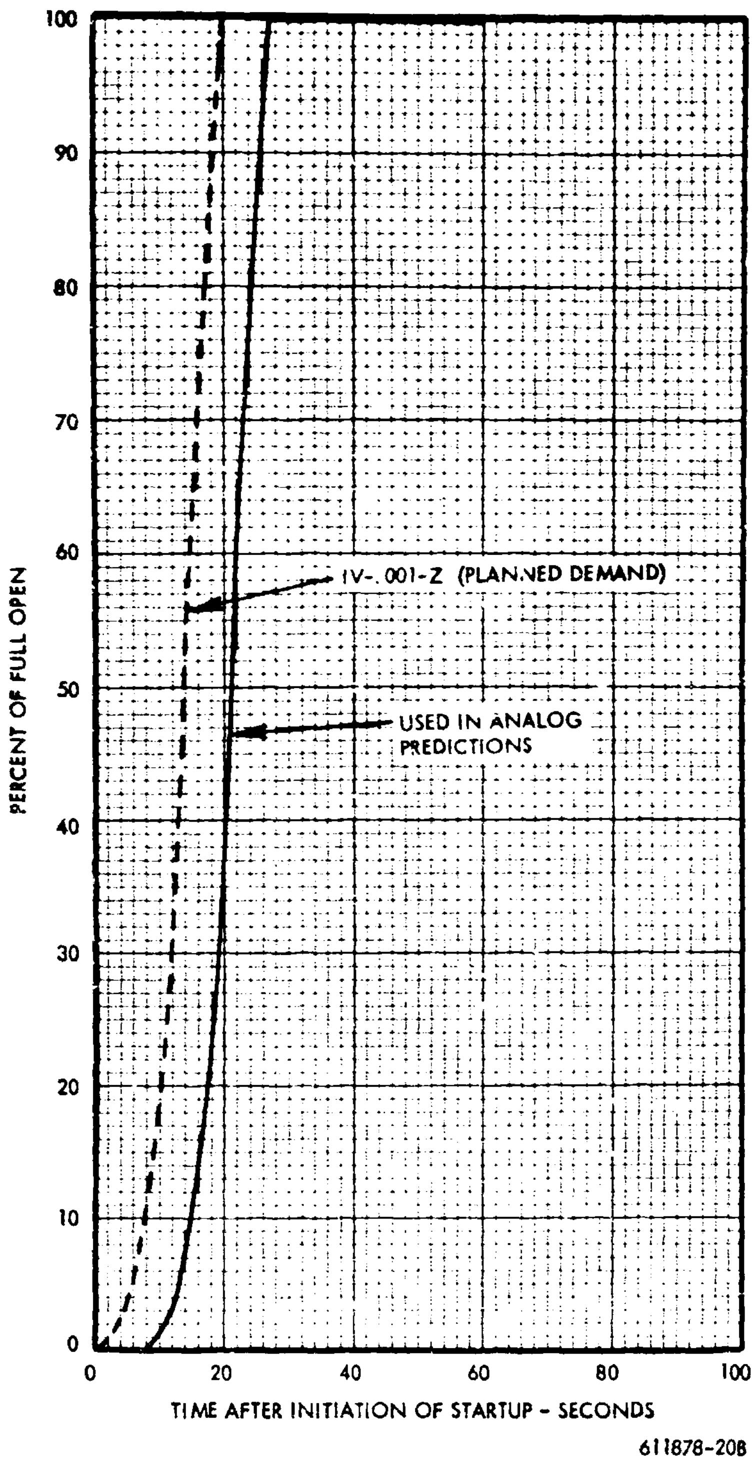

Figure 7-5. L-11 Demand

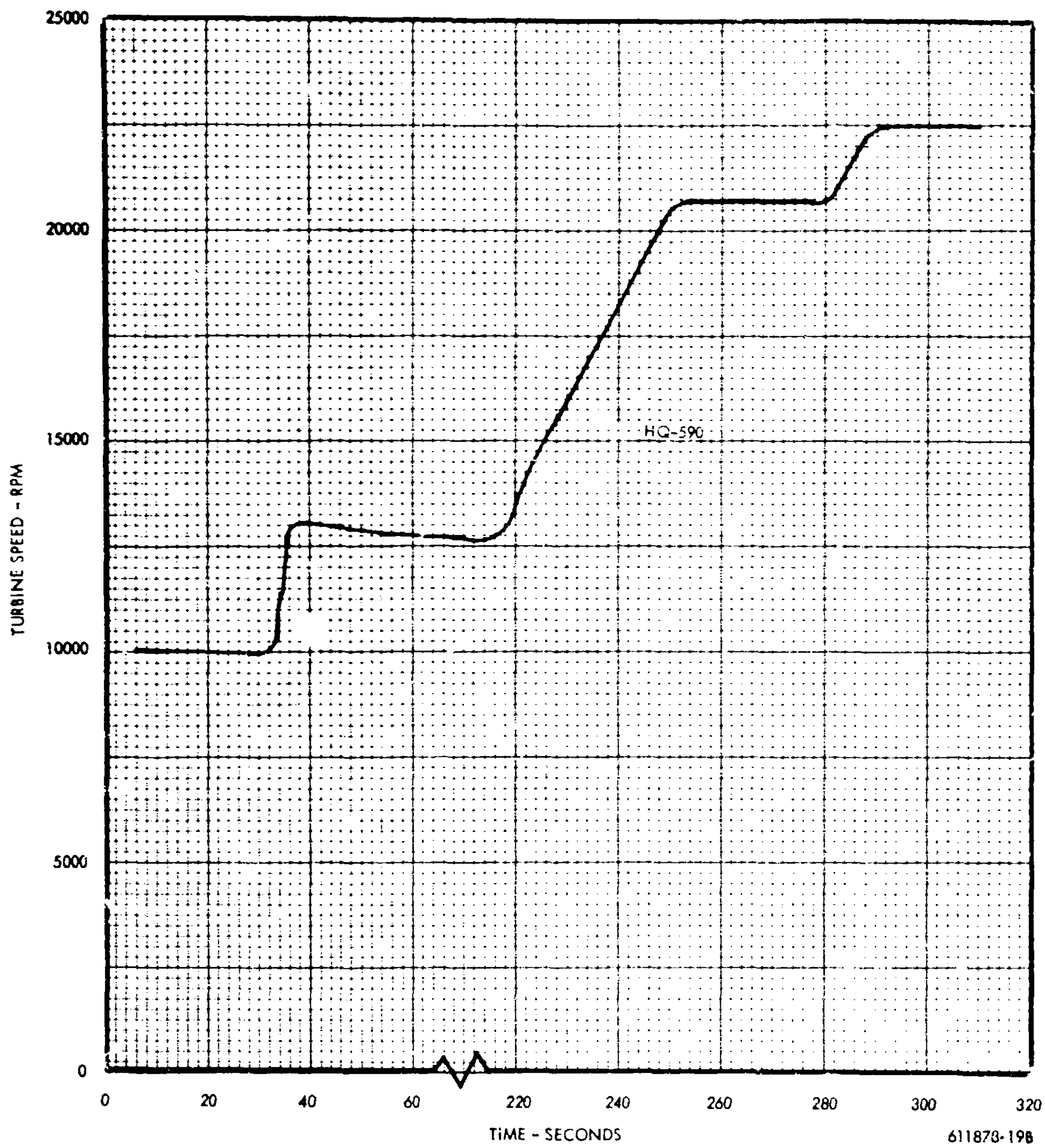

Figure 7-6. St rtup: Turbine Speed

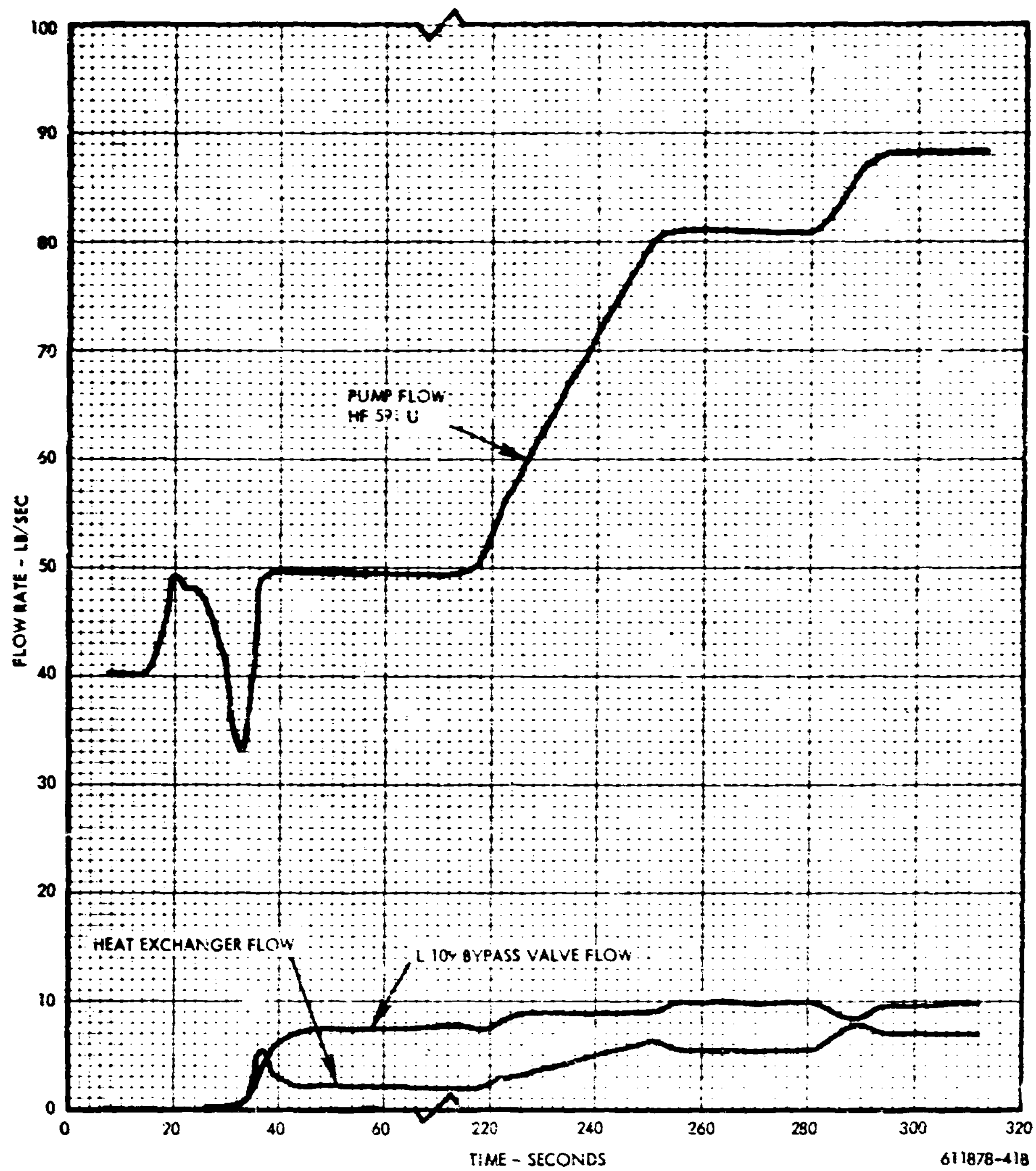

Figure 7-7. Startup: Feedsystem Flow Rates

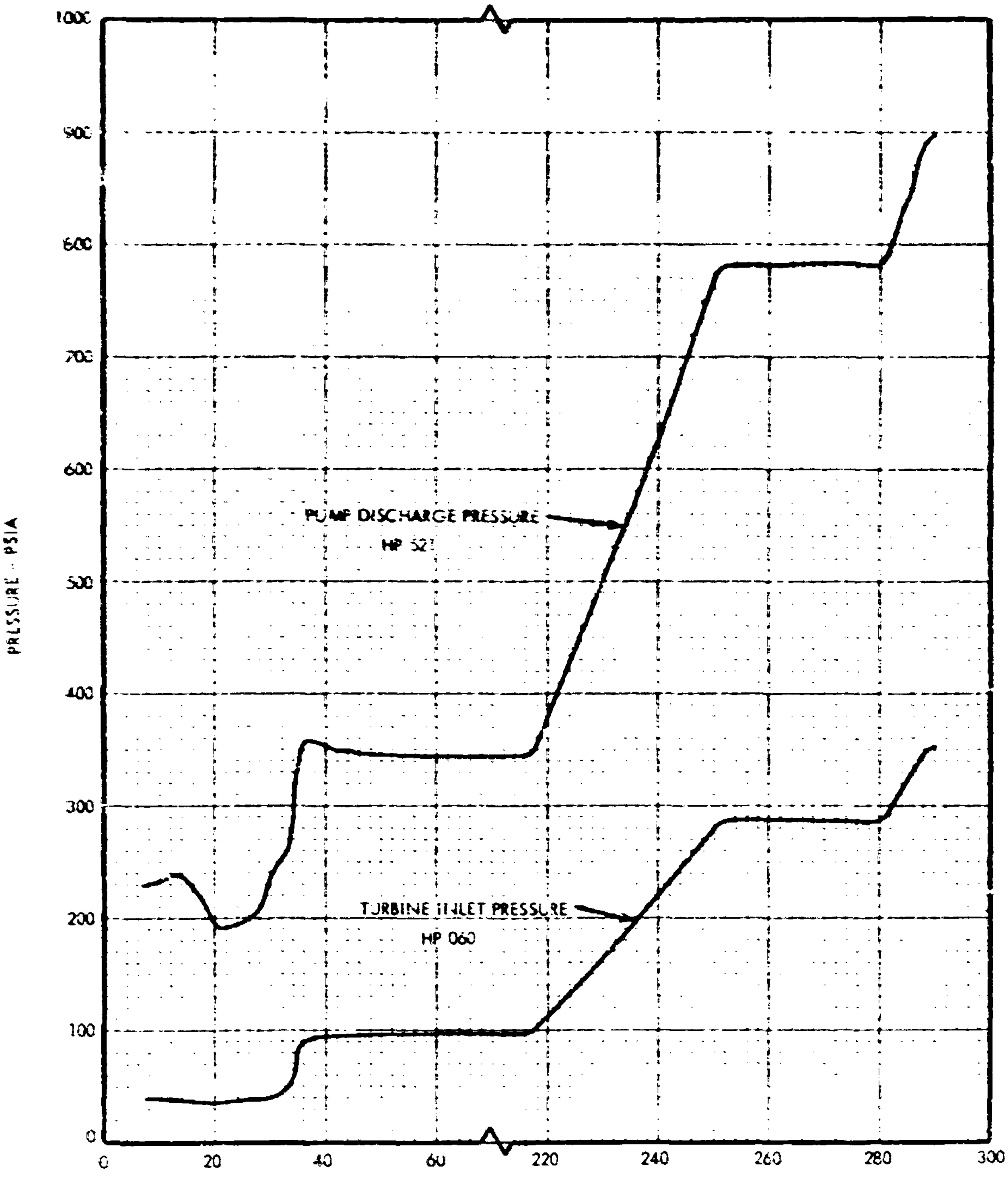

Figure 7-8. Startup: Feedsystem Pressures

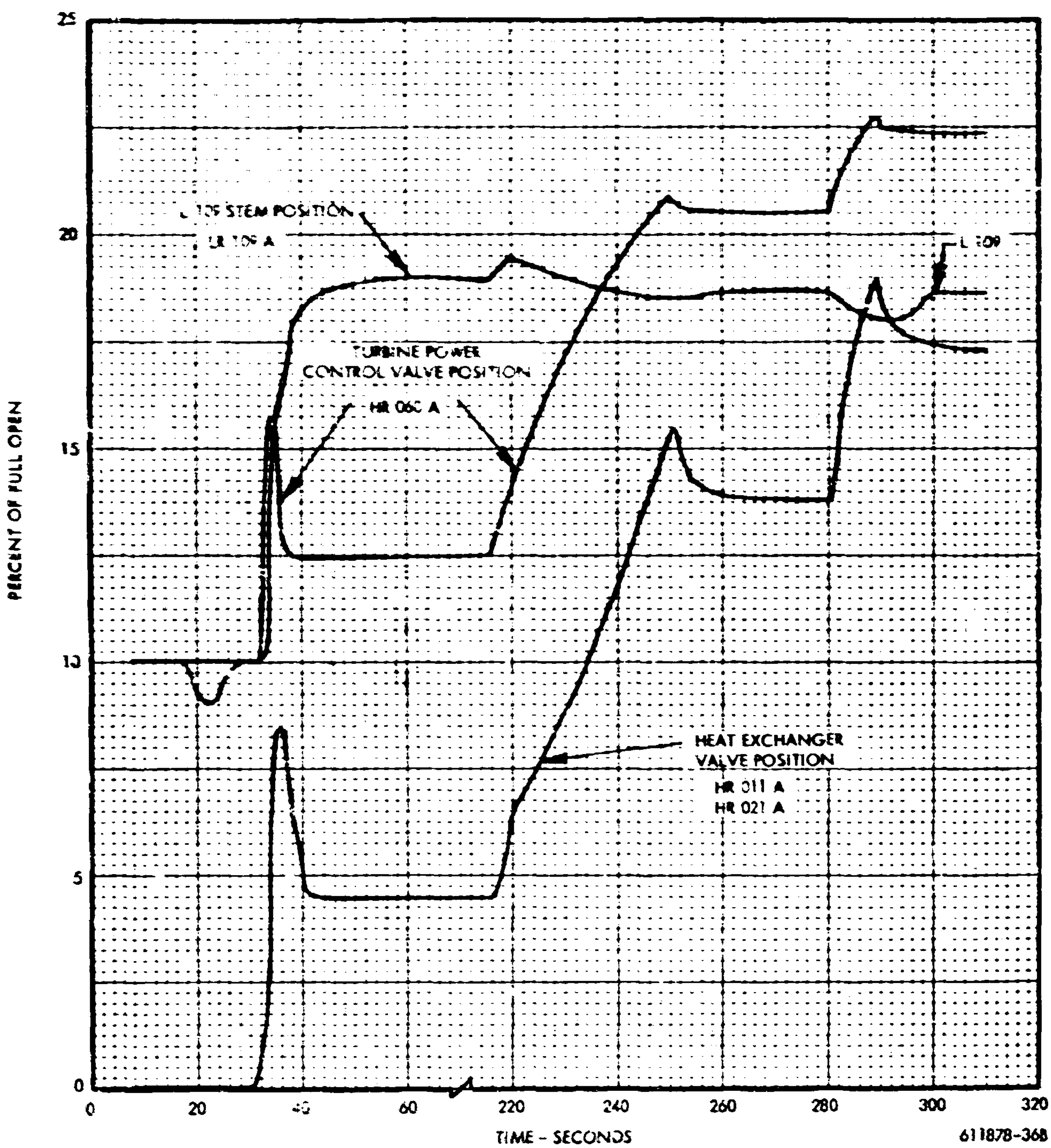

Figure 7-9. Startup: Feedsystem Valve Positions

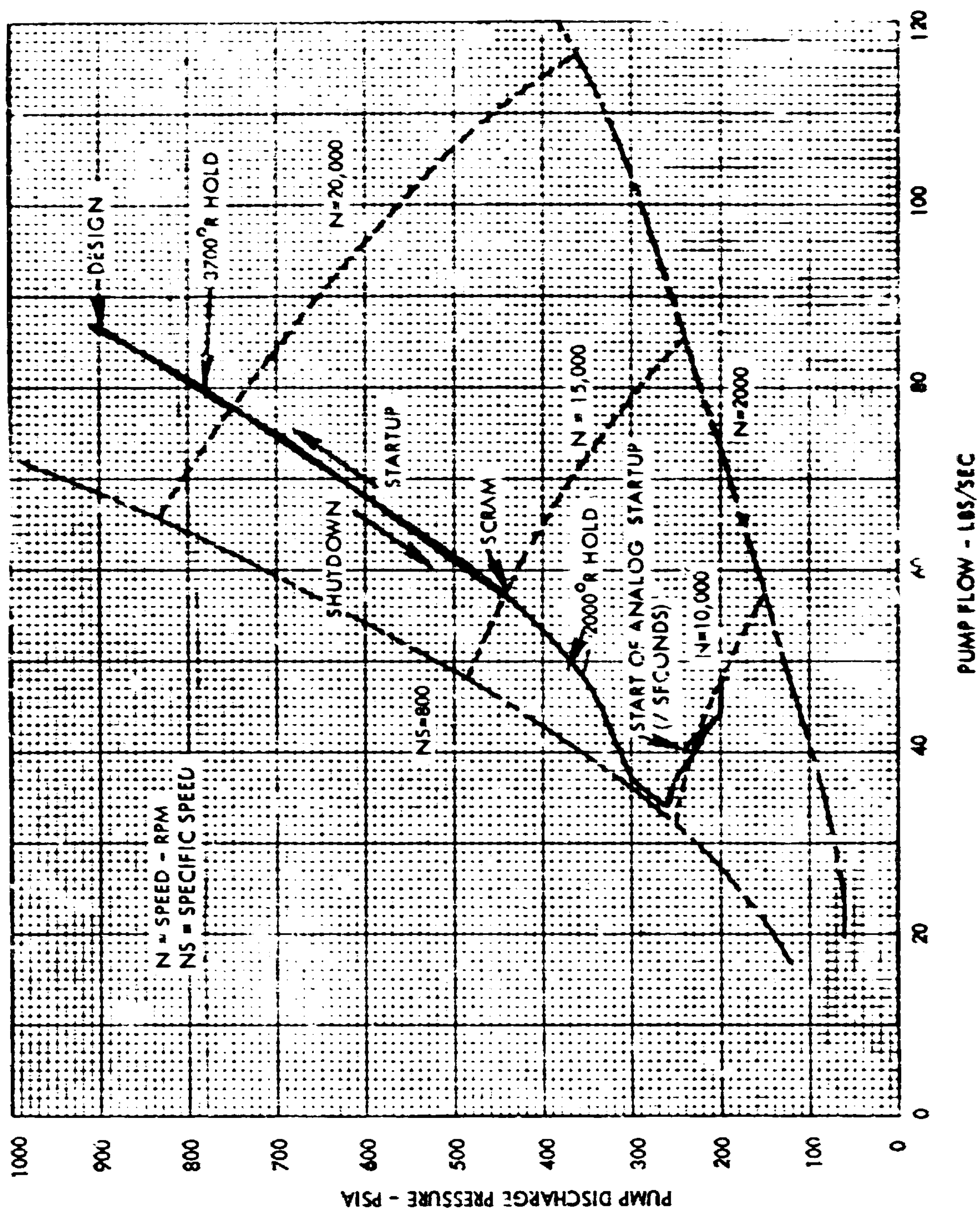

Figure 7-10. Pump Discharge Pressure Vs. Pump Flow

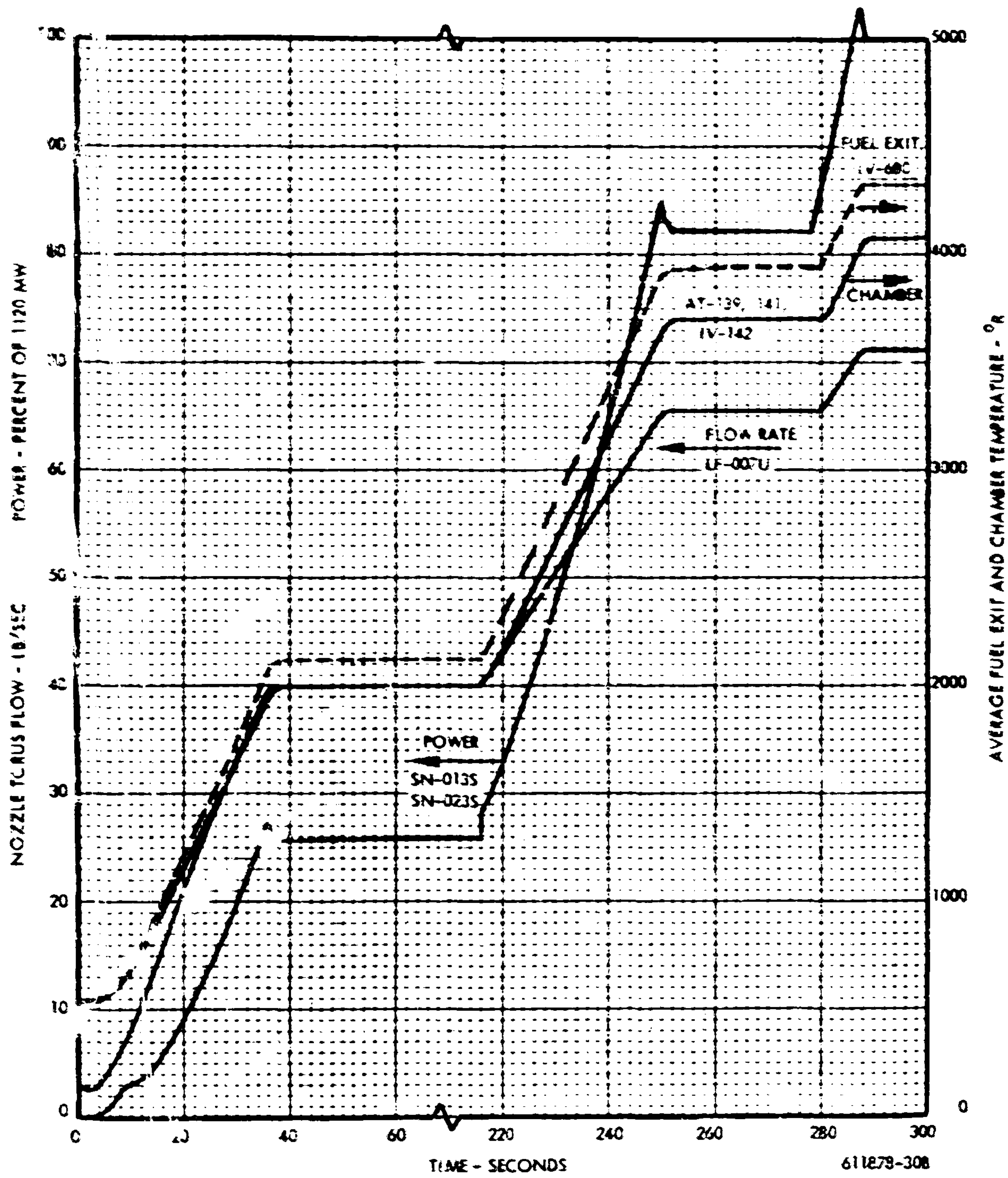

Figure 7-11. Startup: Power, Flow Average Fuel Exit and Chamber Temperature

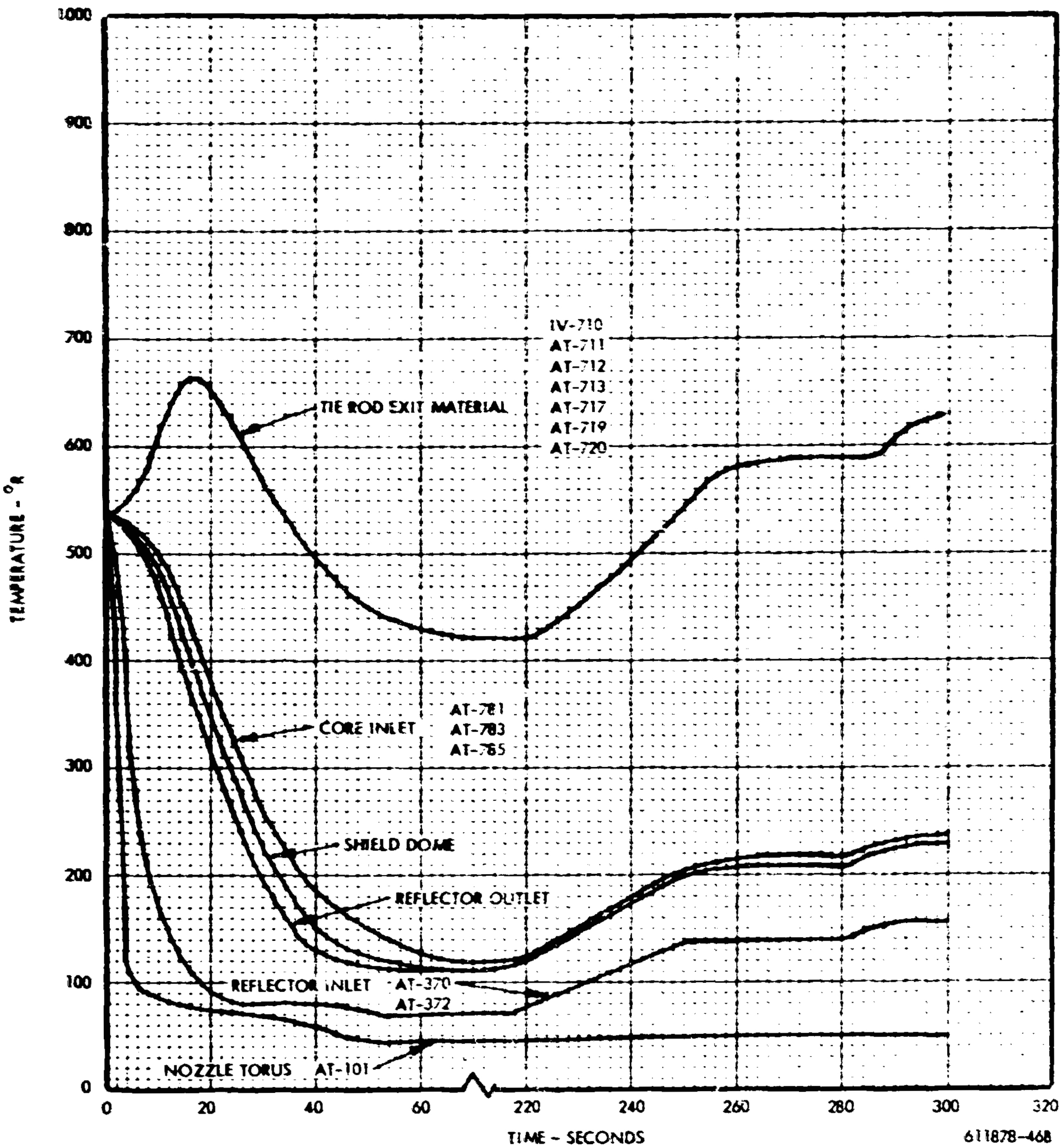

Figure 7-12. Startup: Tie Rod Exit Material and Reflector Plenum Temperature

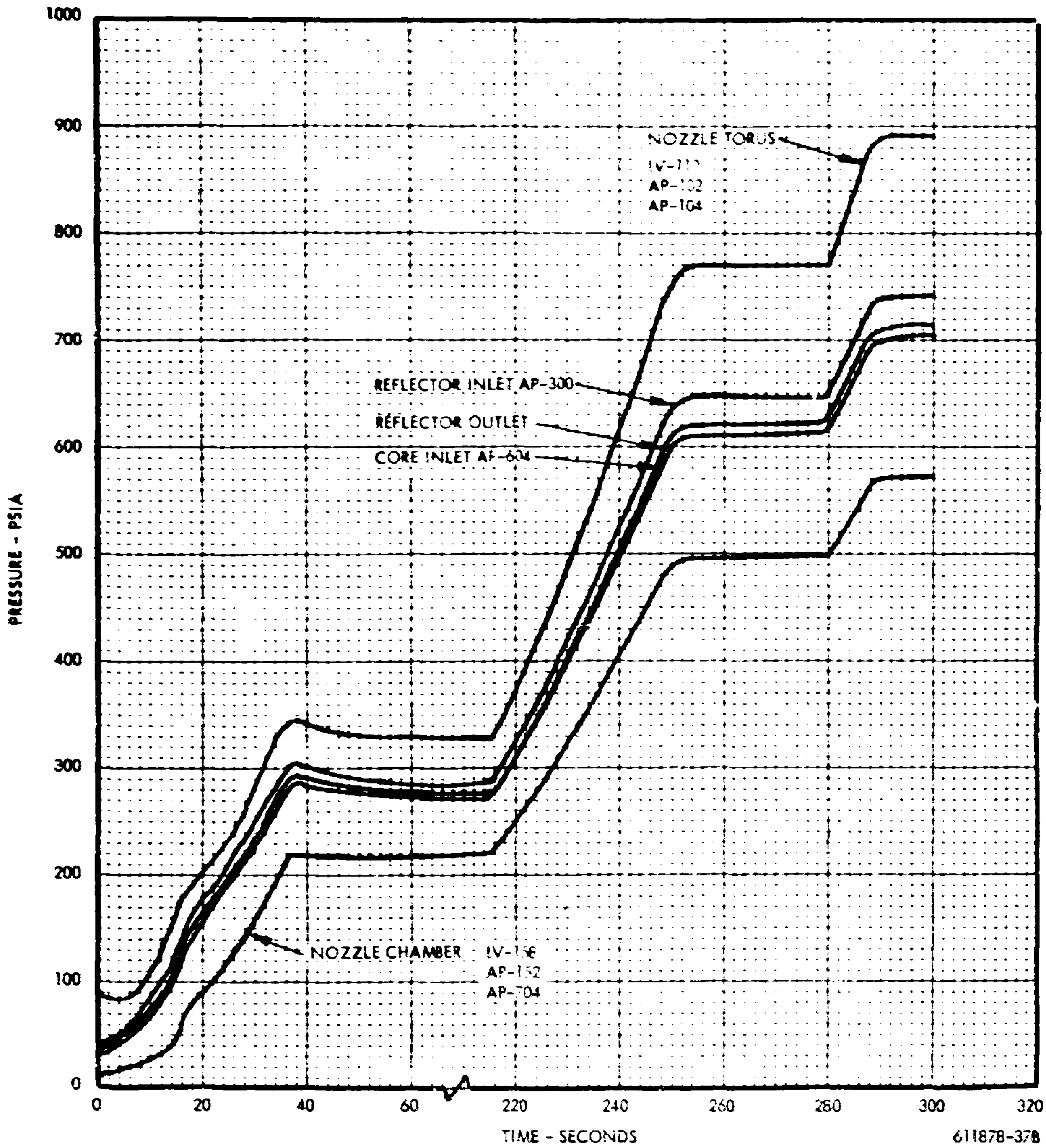

Figure 7-13. Startup: Reactor Plenum Pressures

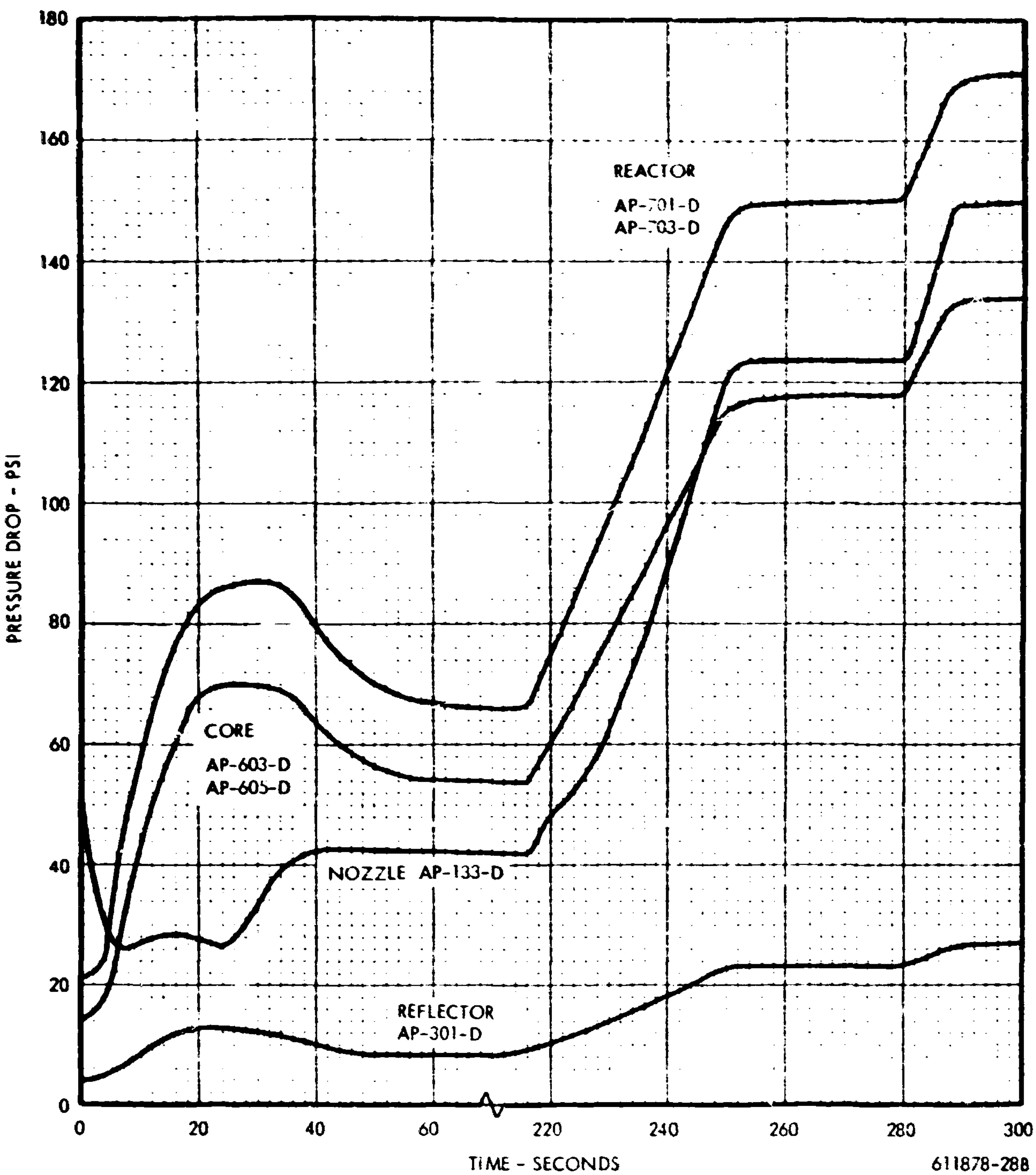

Figure 7-14. Startup: Reactor Component Pressure Drops

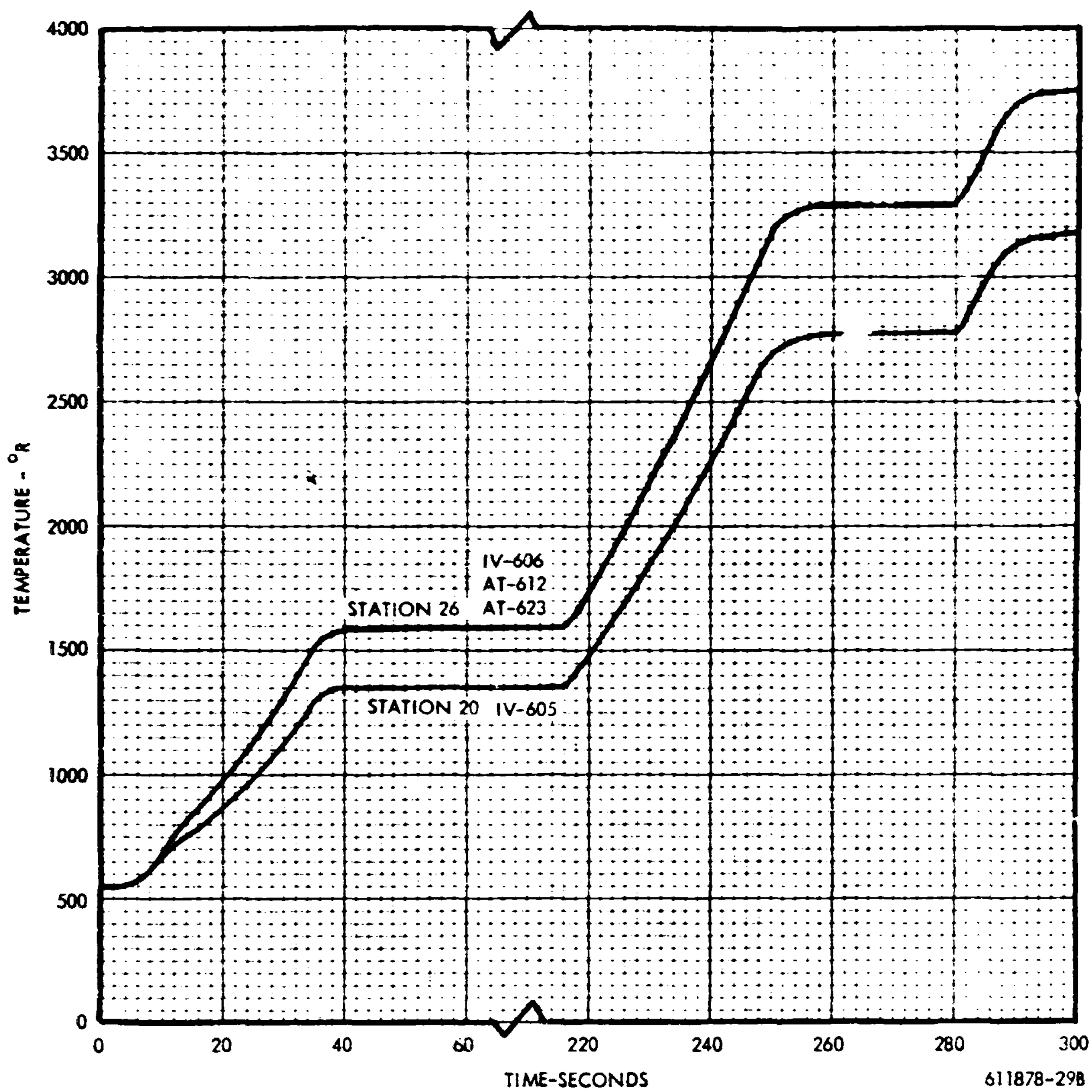

Figure 7-15. Startup: Core Station Temperatures

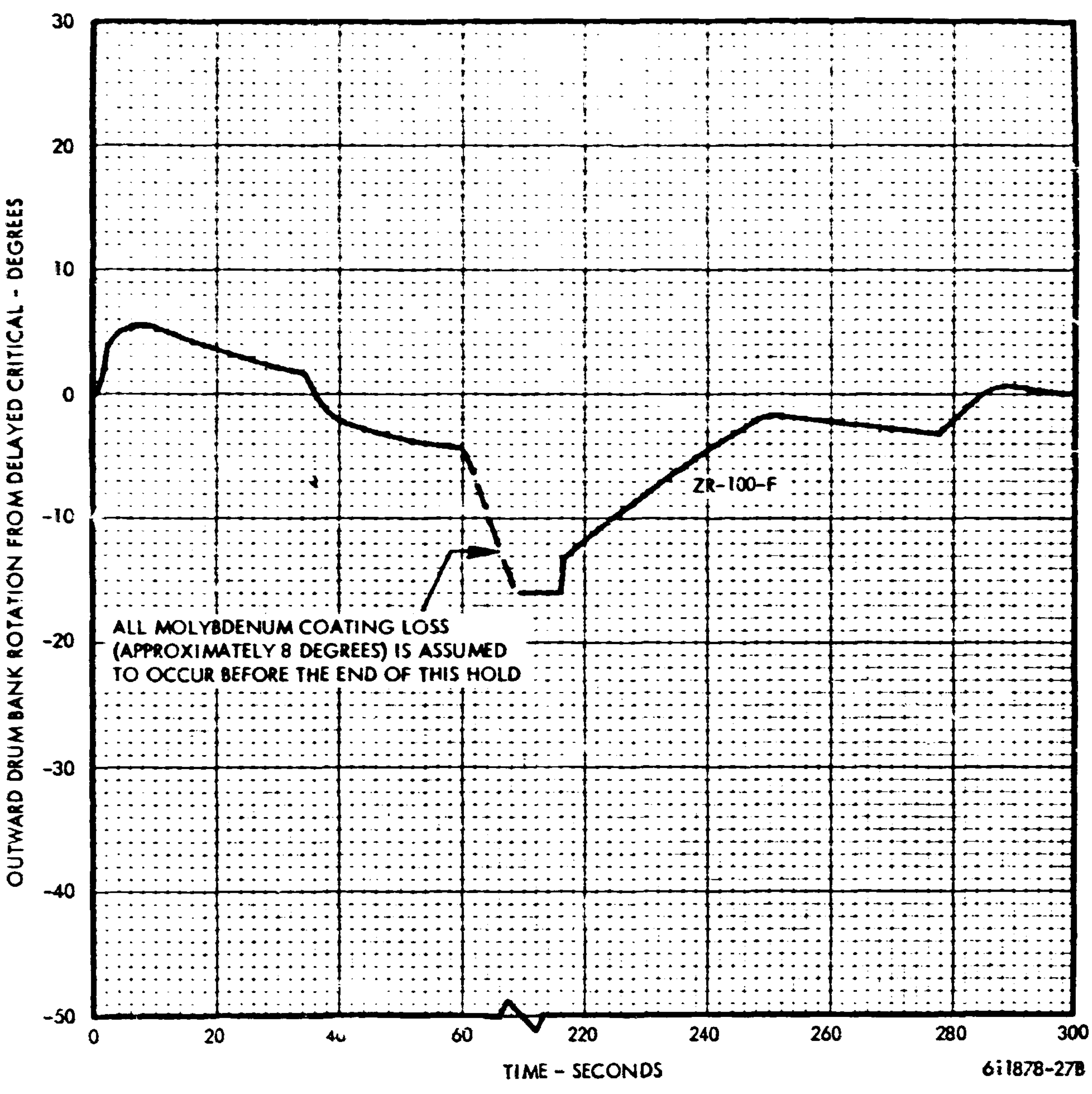

Figure 7-16. Startup: Control Drum Bank Position

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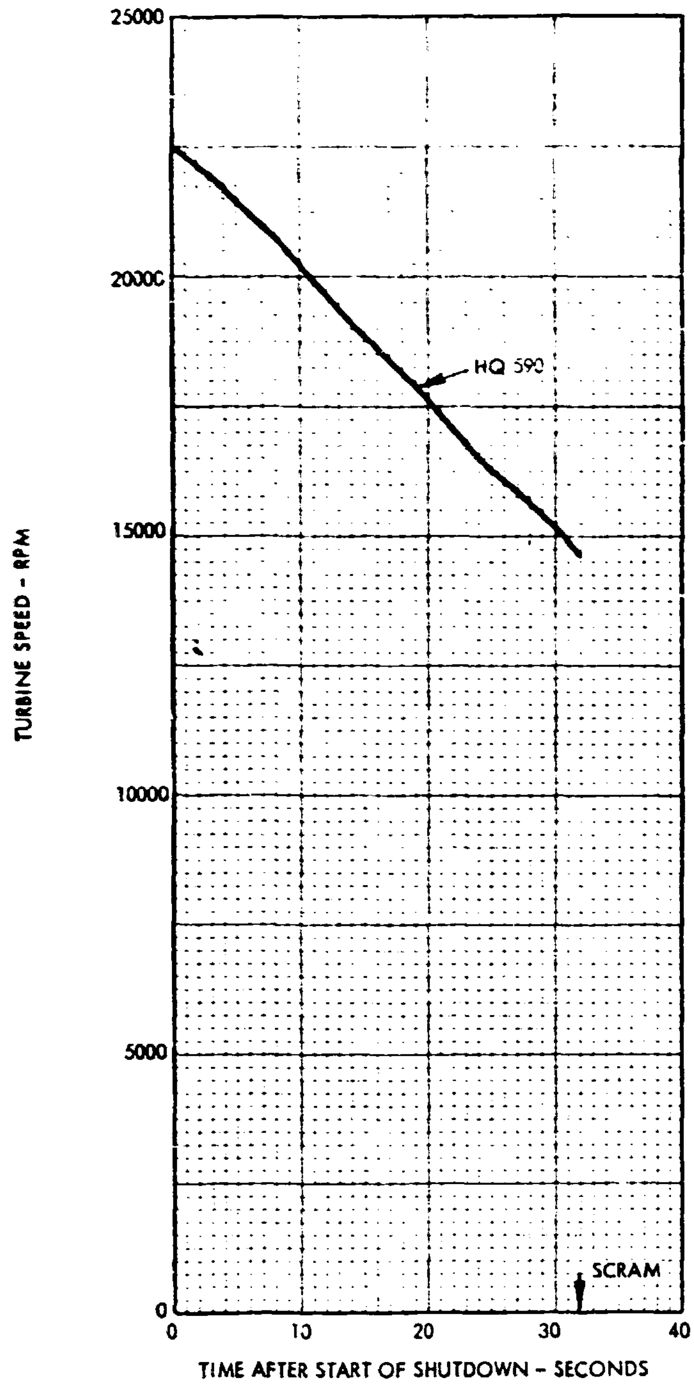

Figure 7-17. Shutdown: Turbine Speed

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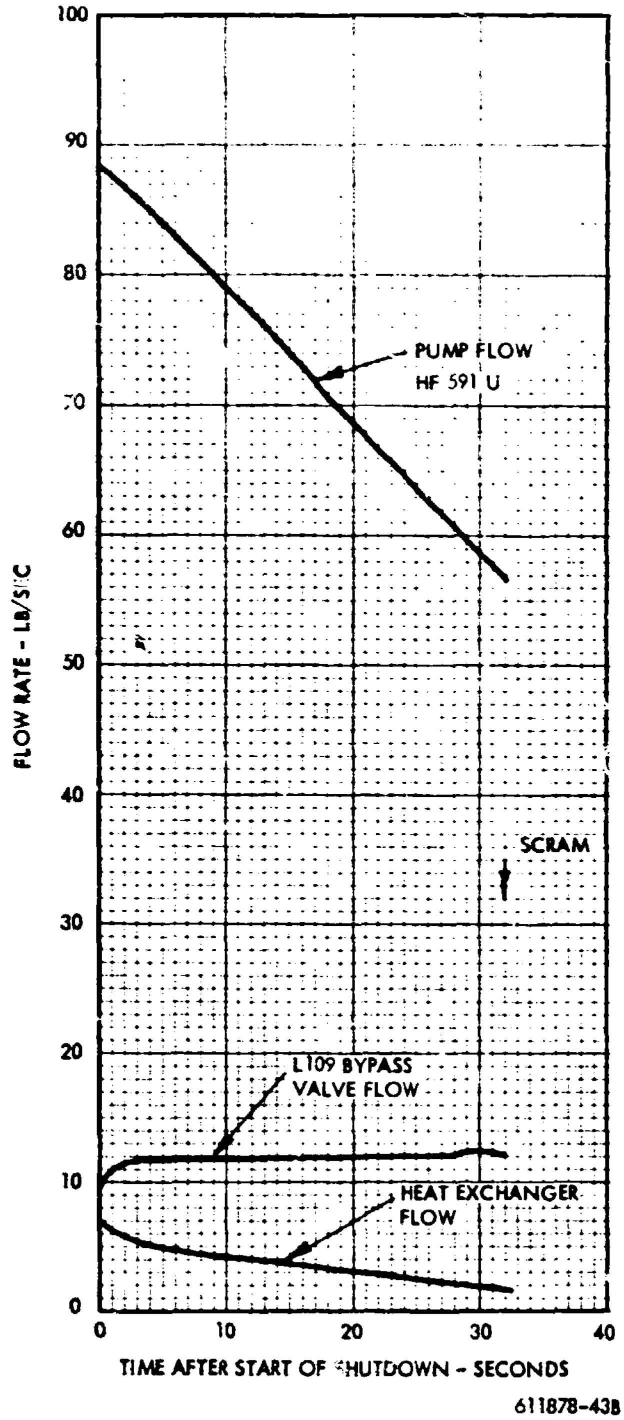

Figure 7-18. Shutdown: Feedsystem Flow Rates

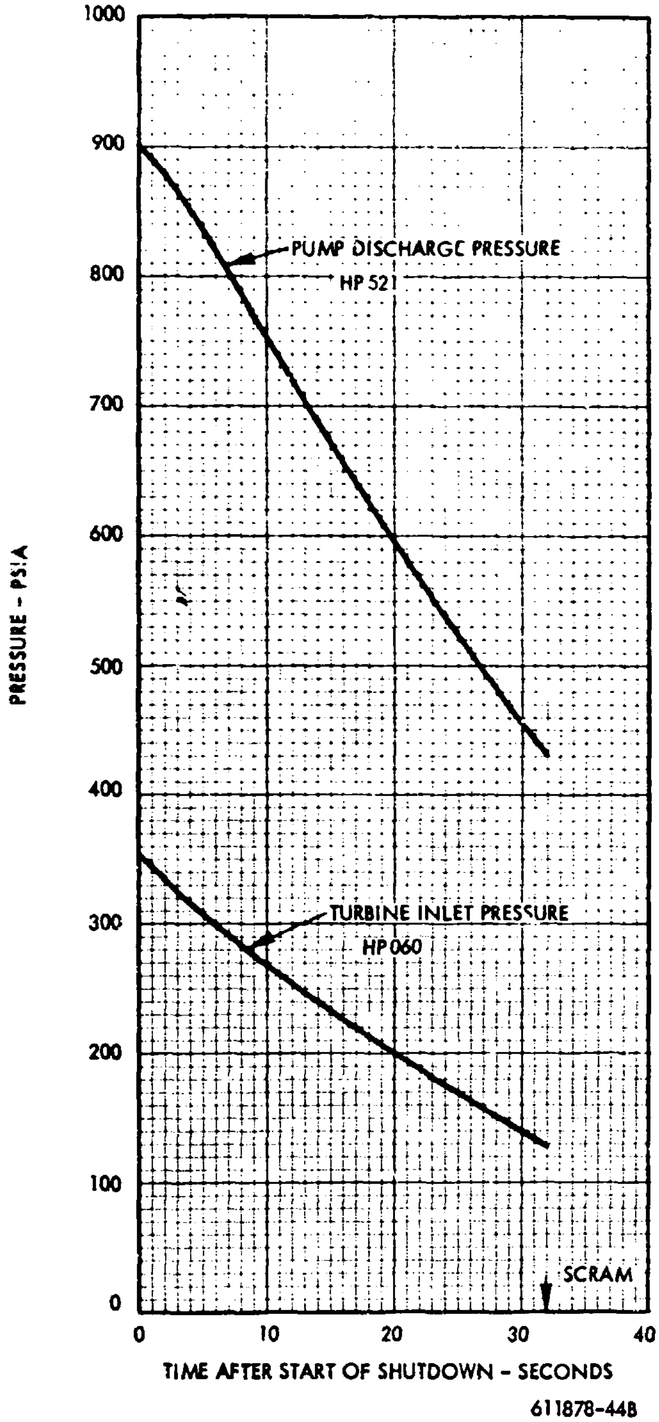

Figure 7-19. Shutdown: Feedsystem Pressures

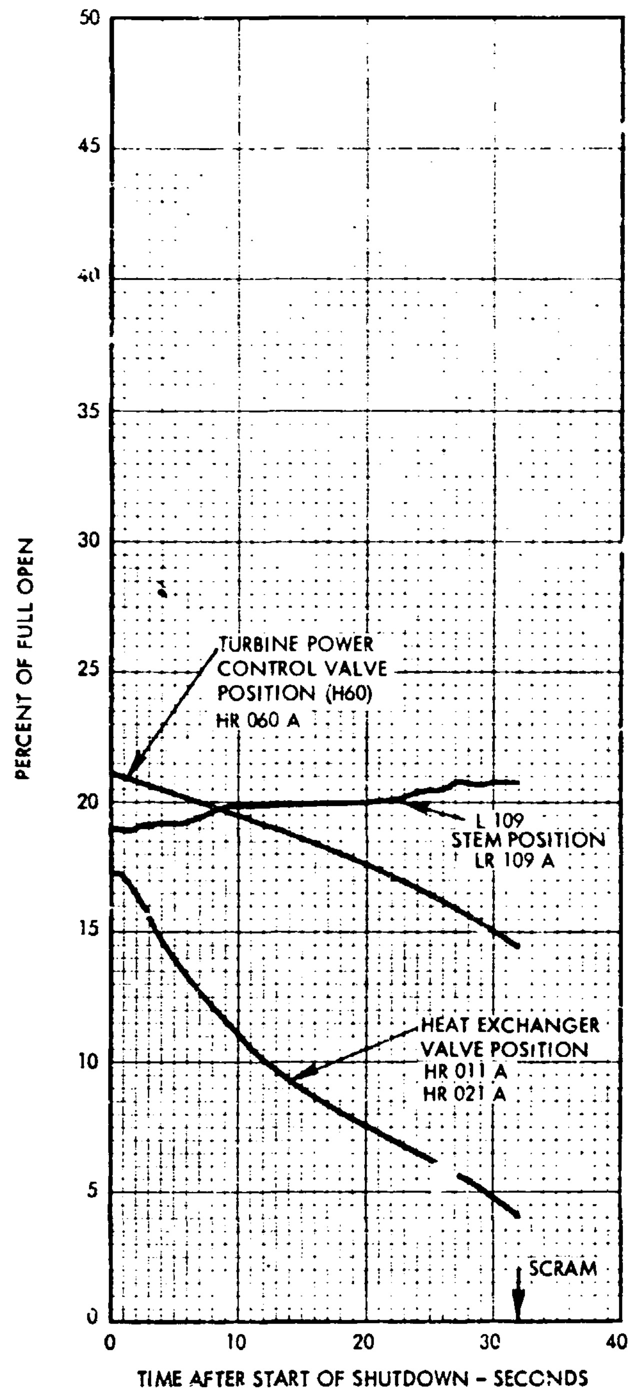

Figure 7-20. Shutdown: Feedsystem Valve Positions

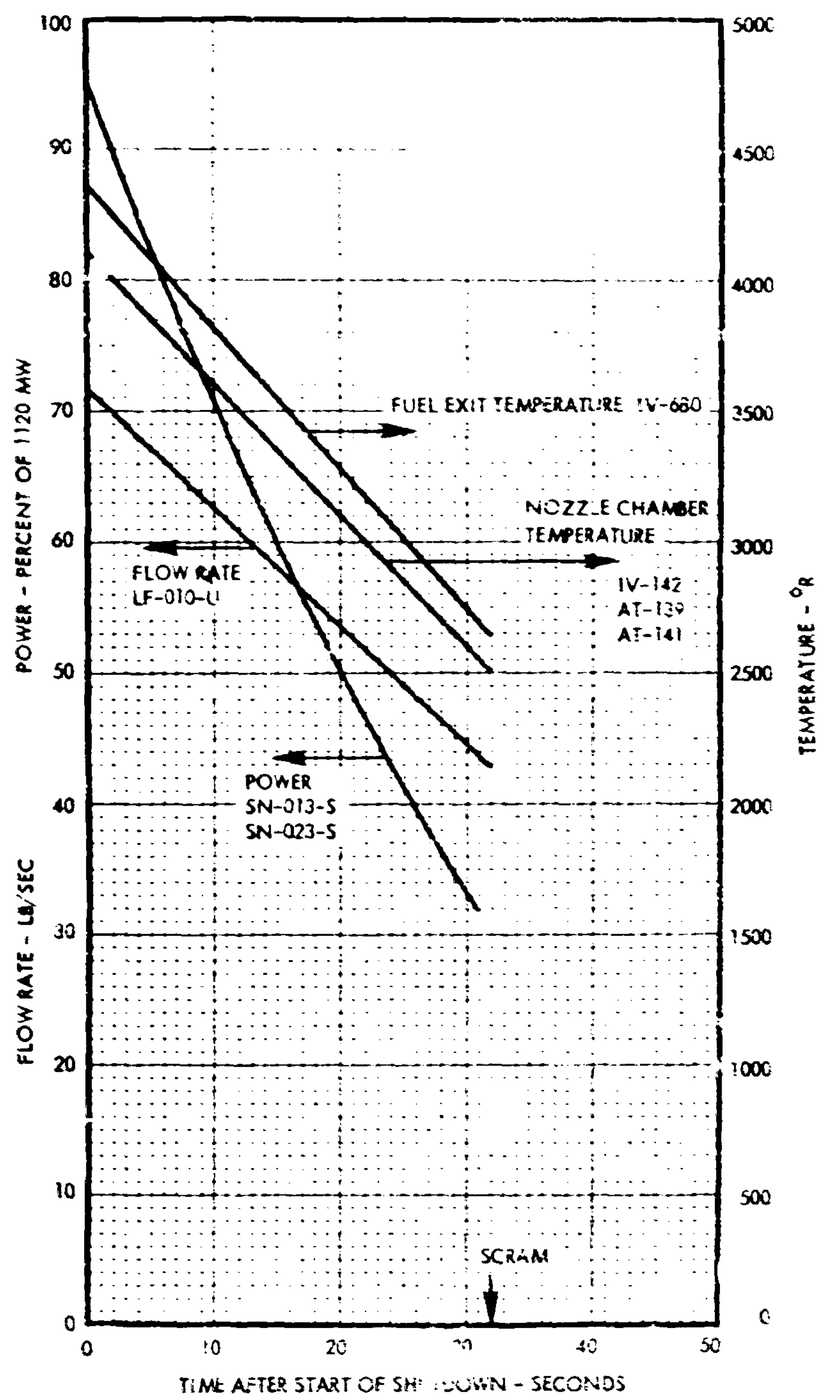

Figure 7-21. Shutdown: Power, Flow, Average [illegible] Temperature

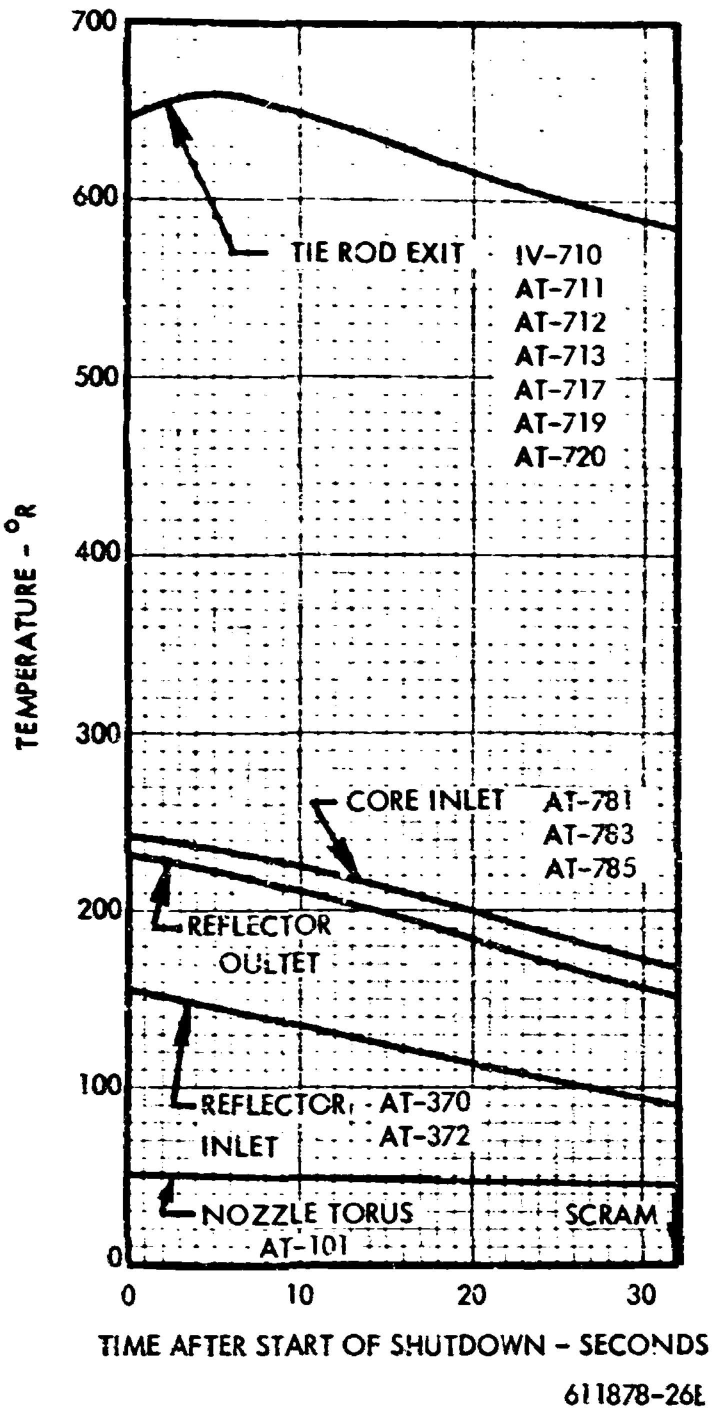

Figure 7-22. Shutdown: Tie Rod Exit Material and Reactor Plenum Temperatures

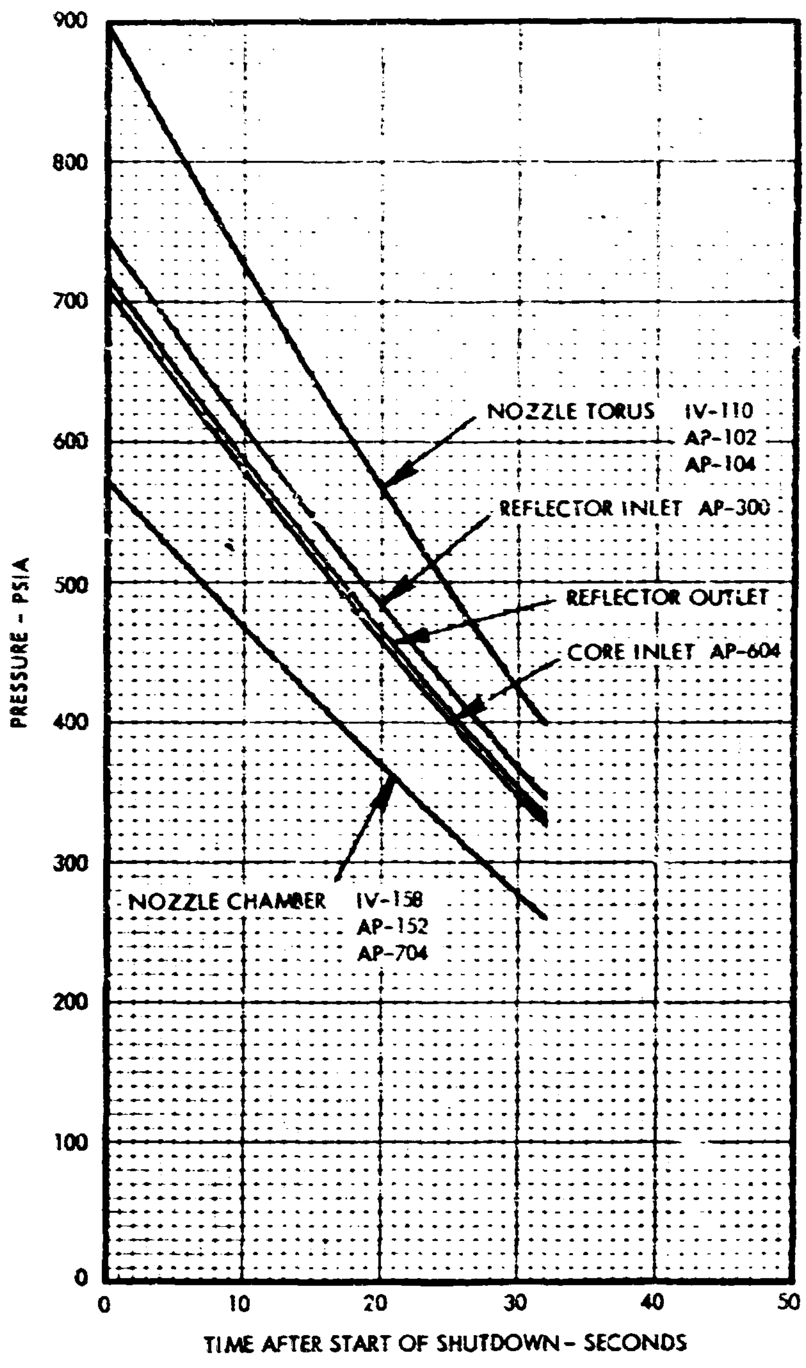

Figure 7-23. Shutdown: Reactor Plenum Pressures

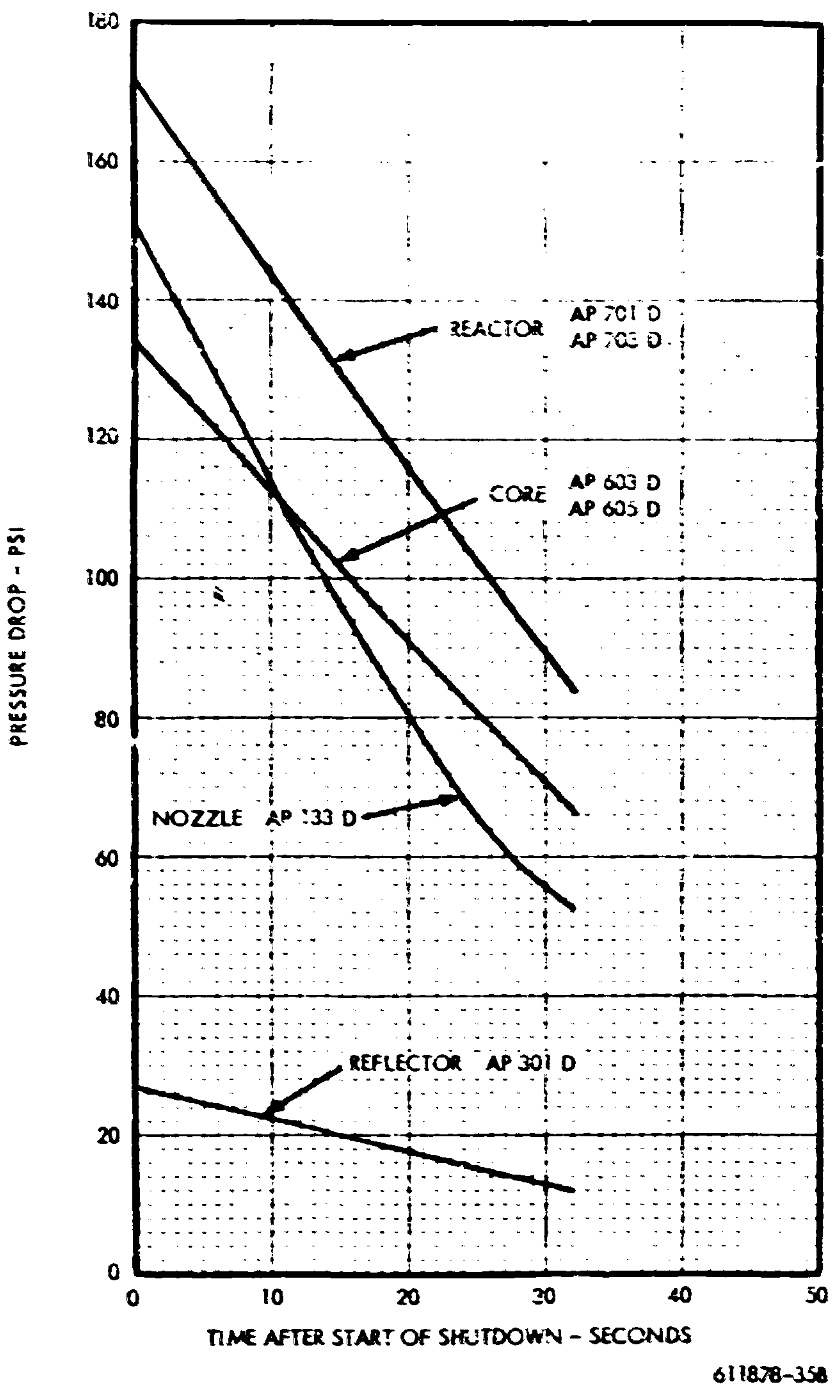

Figure 7-24. Shutdown: Reactor Component Pressure Drops

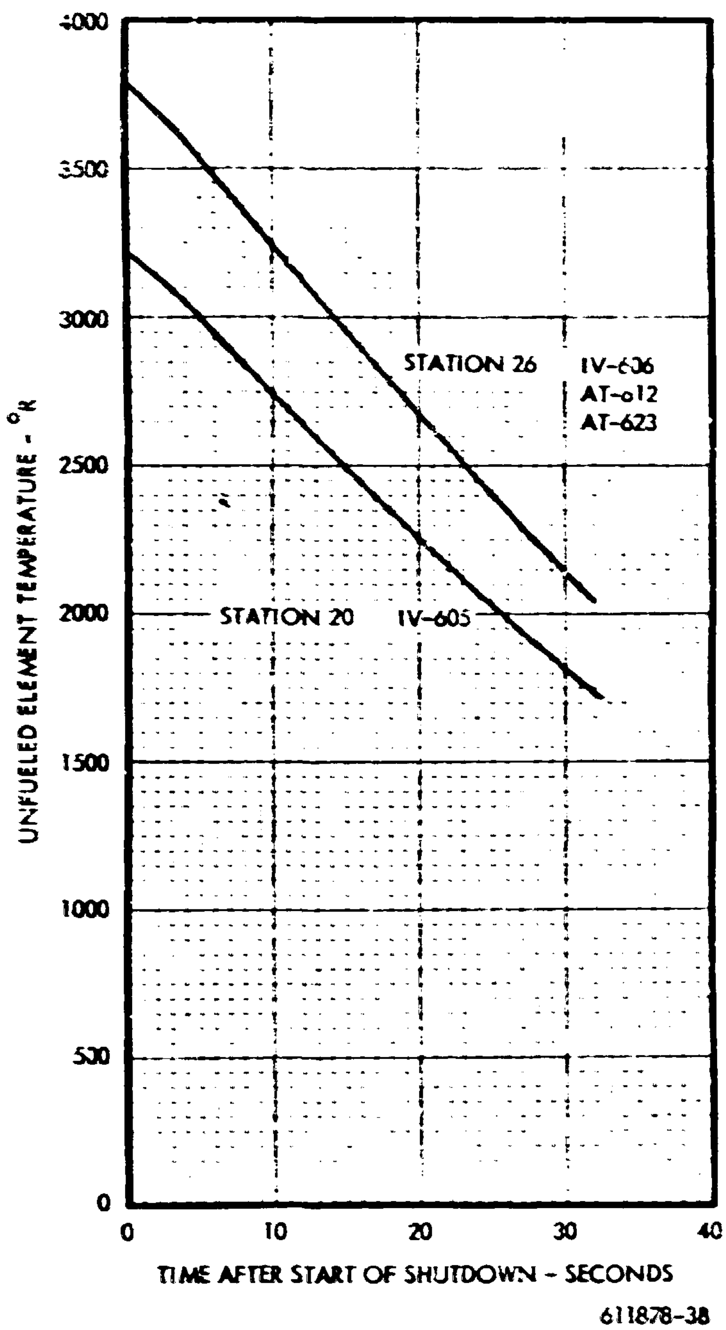

Figure 7-25. Shutdown: Core Station Temperatures

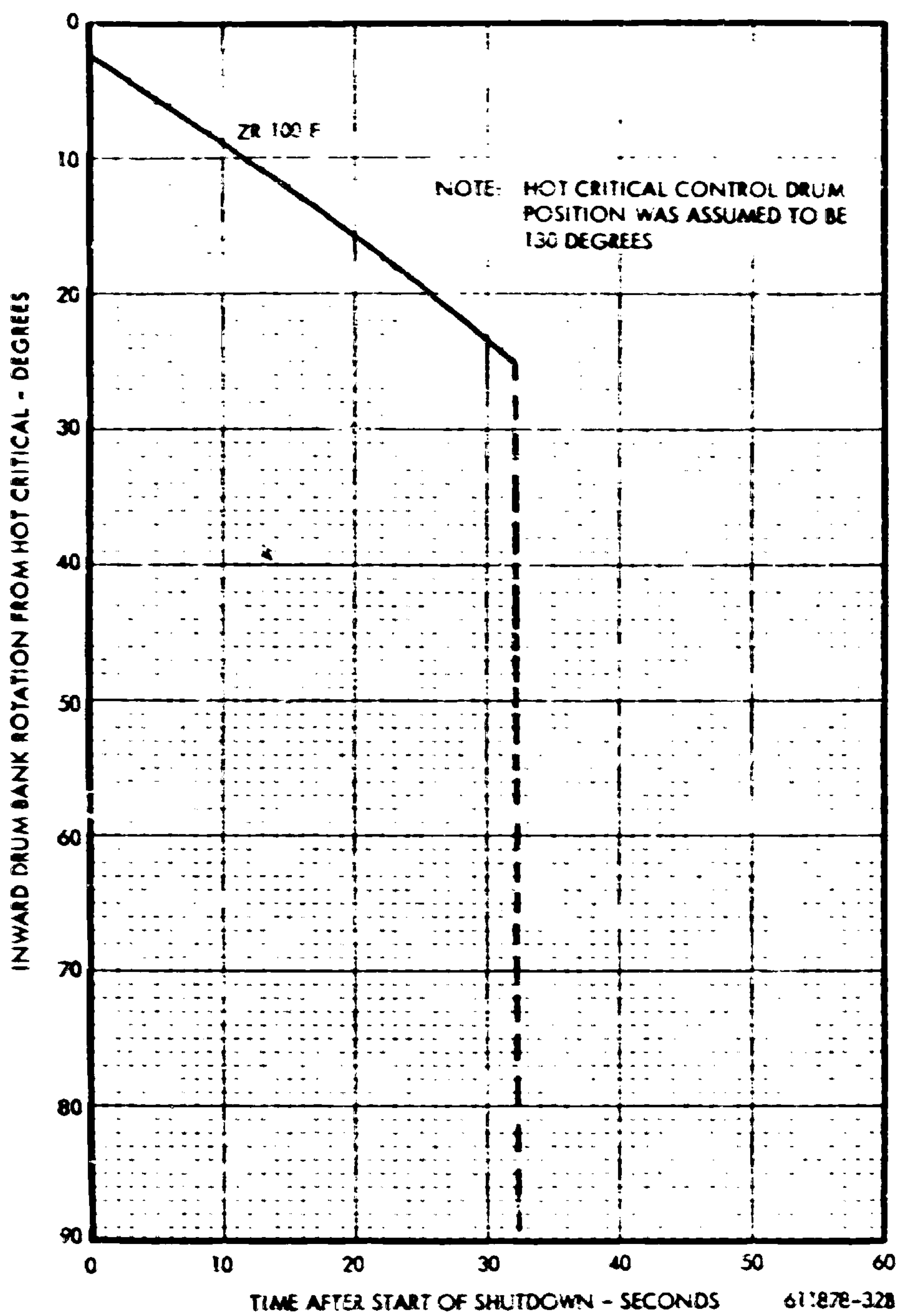

Figure 7-26. Shutdown: Control Drum Bank Position

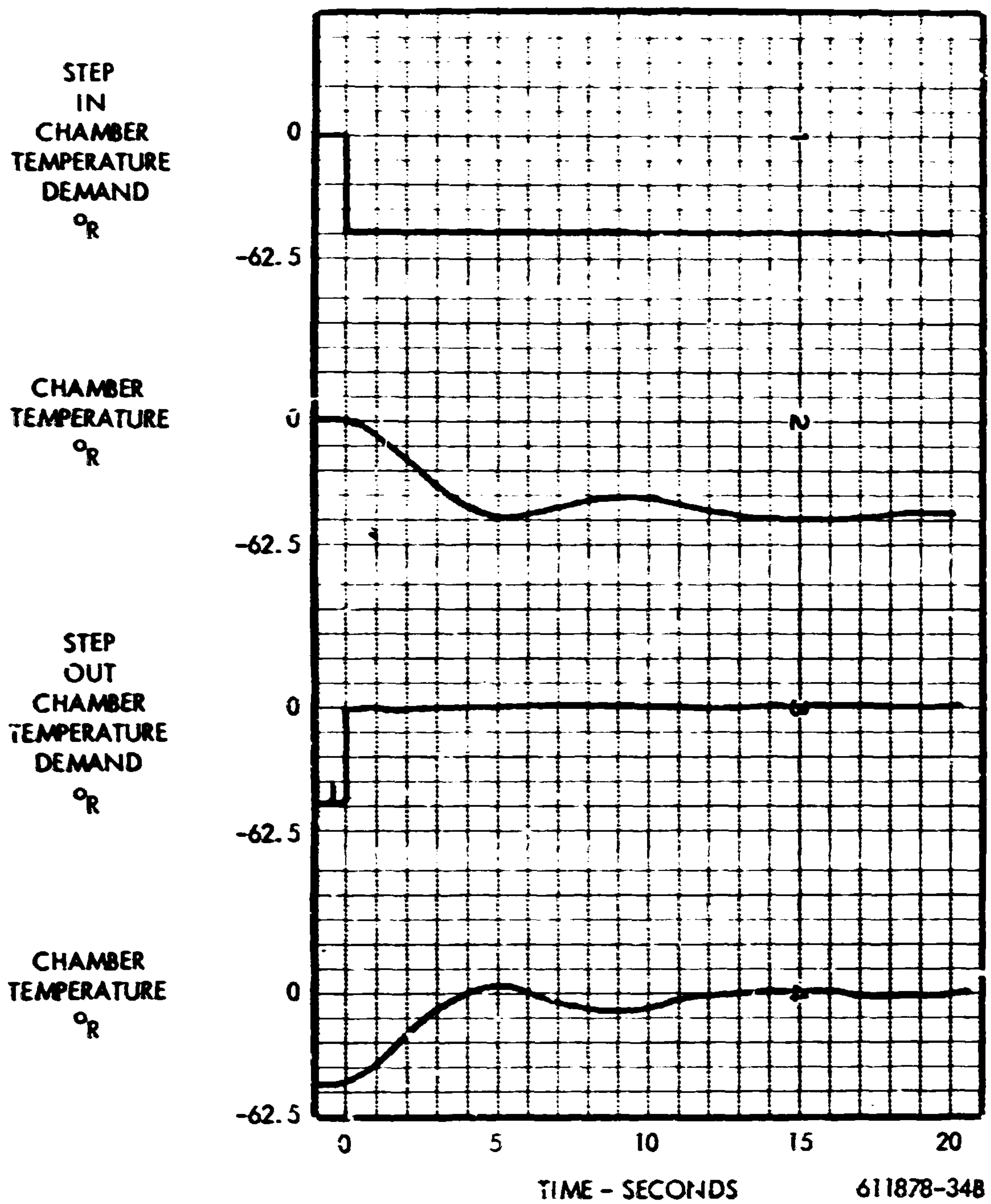

Figure 7-27. Chamber Temperature Step Response

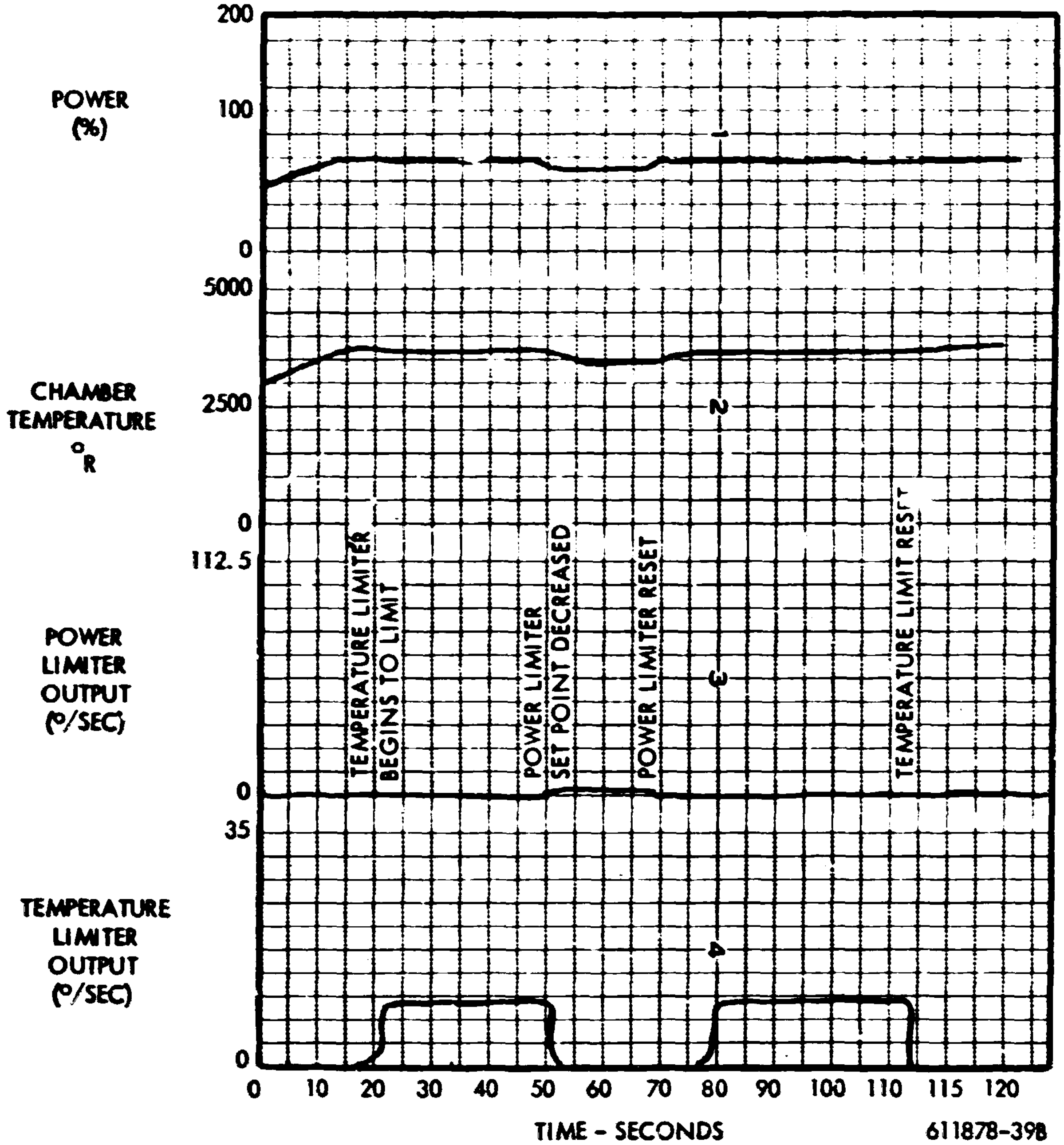

Figure 7-28. Temperature and Power Limiter Checkout

8.0 COOLDOWN

The decay power, decay energy, cooldown procedure and coolant usage are presented in this chapter. The cooldown procedure is consistent with present NTO plans. In general, considerable latitude in coolants and/or procedure is possible during cooldown as long as reactor conditions are maintained within the limitations listed in Chapter 3. Prediction data are given for run durations of 30,45, and 60 minutes at rated conditions.

8.1 Decay Power and Energy

The total decay power, delayed neutron fission plus gamma and beta decay, is shown in figure 8-1 for 30, 45, and 60 minute operating times at rated conditions. The decay power for each of these cases also considers the fission power generated during startup and shutdown. The startup and shutdown power profiles which were used for the calculation are shown in figures 7-11 and 7-20. The delayed neutron power is based on about 4.7$ of shutdown reactivity. This shutdown reactivity is based on an assumed 2.2$ reactivity loss during the test, 1$ net positive feedback reactivity during cooldown, and the worth curve of control drums (see figure 5-10). The gamma and beta decay power was computed with Revision 1 of the S-4 (Fission Product Energy Release) code. The decay power is shown as a function of time after scram which occurs at 2500^{o}R chamber temperature.

The total decay power for each case has been integrated with time to determine the decay energy as a function of time after scram. The total decay energy is shown as a function of time after scram in figure 8-2 for the three cases 30, 45, and 60 minute full power operating times). The data in this figure were used to compute the coolant requirements given in Section 8-2.

8.2 Cooldown Procedure and Coolant Usage

The purpose of this section is to both describe the cooldown procedure and also to present the corresponding coolant usage. The cooldown procedure was developed with the help of NTO engineering. The coolant usage is presented in two ways: the flow rates for the continuous flow phases and the total coolant requirement for the pulse cooling phase. Table 8-1 shows the power dissipation capabilities of the coolants that may be used during cooldown (liquid hydrogen, ambient hydrogen, liquid nitrogen, and ambient nitrogen) for nozzle chamber temperatures of 1400, 1200, 1000, and 800°R. The cooling effectiveness is presented in two ways: (1) the power dissipated by 1 lb/sec flow of each coolant at the chamber temperatures considered and (2) the flow rate of ambient hydrogen, liquid nitrogen, and ambient nitrogen which is equivalent (based on equal heat removal capabilities) to a liquid hydrogen flow of 1 lb/sec. This data is useful to determine the times when coolants can be switched.

For this report, the start of cooldown will be defined as the time of reactor scram. Reactor scram will occur at 2500°R chamber temperature following a 50°R/sec shutdown. The entire cooldown may be sub-divided into the following four sequential phases:

1) Liquid Hydrogen Flow from the High Pressure Dewar

Flow from dewar 3 (high pressure dewar for emergency cooling) is initiated simultaneously with scram. The flow rate from dewar 3 will depend on the dewar 3 pressure profile and other design parameters which have not been finalized. Predictions for this phase of cooldown will be issued in a supplement.

Flow from dewar 3 is expected to continue until the exit pressure has decreased to below the 90 to 100 psig operating pressure of dewars 4 and 5 (K-system, low pressure liquid hydrogen dewars for cooldown). At this time, flow will switch automatically from dewars 3 to dewars 4 and 5. This switch is automatically performed by check valves.

The dewar 3 shutoff valve (X-3) will be closed after an adequate flow rate is observed from dewars 4 and 5. The locations of these check valves and X-3 are shown in figure 4-13.

This phase is estimated to require approximately 25 seconds, and the chamber temperature at the end of this phase estimated to be 1200°R.

2) Liquid Hydrogen Flow from the Low Pressure Dewars

The initial flow from dewars 4 and 5 will be determined by the 90 to 100 psig dewar pressure and the flow resistance of the line and the reactor. An initial flow of approximately 14 lb/sec is expected. This flow rate exceeds the flow rate required to maintain 1200°R chamber temperature at 25 seconds after scram. Manual control of K-6 will be used to control flow to maintain approximately 1200°R chamber temperature. After a flow rate of 5 lb/sec is reached it will be held constant until the chamber temperature is reduced to approximately 1000°R.

The required flow rates as functions of time after scram for run durations of 30, 45, and 60 minutes at rated conditions based on the assumed chamber temperature (1200°R for flow rates above 5 lb/sec and 1000°R for a flow rate of 5 lb/sec) are shown in figure 8-3. The following table summarizes the length of this phase for the three cases considered:

Operating Time at Rated Conditions Prior to Shutdown (Minutes)	Termination Time of LH_2 Flow - (Seconds after Scram)	Length of LH_2 Flow - (Seconds)
30	140	115
45	170	145
60	190	165

3) Transition from Liquid to Gaseous Hydrogen Flow

The mixing chamber will be utilized to make the transition to ambient hydrogen flow. At a constant mixing chamber flow rate of 5 lb/sec, G-3 will be manually opened to start and then to increase ambient hydrogen flow. Ambient hydrogen will be increased in a stepwise manner. Therefore the chamber temperature will not remain constant and will probably vary between 800 and 1200°R. The end of this phase will be when 5 lb/sec of ambient hydrogen flow is sufficient to maintain 1000°R chamber temperature.

Predictions were made for this phase assuming 1000°R chamber temperature and a continuous transition to ambient hydrogen flow. The required liquid and ambient flow rates are shown in figure 8-3. The following table summarizes the length of this cooldown phase for the three full power run durations considered:

Operating Time at Rated Conditions (Minutes)	Termination Time of GH_2 Flow - (Seconds After Scram)	Length of Transition Phase (Seconds)
30	540	400
45	670	500
60	800	610

4) Pulse Cooling with Liquid Nitrogen

Pulse cooling with liquid nitrogen at a flow of approximately 30 lb/sec will be initiated at the time the mixing chamber exit temperature has been increased to near ambient. The data in table 8-2 shows that for a 1000°R chamber temperature, 26 lb/sec of liquid nitrogen is equivalent in heat removal capability to 5 lb/sec of ambient hydrogen. Therefore, the transition to liquid nitrogen may be safely done at this time. Ambient hydrogen flow will be discontinued by closing G-3, and liquid nitrogen will be initiated by opening N-30. The first pulse will continue unitl the desired end of pulse reactor temperature level has been achieved. At this time liquid nitrogen flow will be discontinued by closing N-21. The piping volume from N-21 to the nozzle torus is approximately 40 $ft.^3$ Approximately 1760 pounds of liquid nitrogen may remain in this pipe at the conclusion of a pulse. The boil-off of this quantity of liquid nitrogen will continue to cool the reactor for some time after the pulse control valve (N-21) is closed. The pulse flow termination criteria of 450°R tie rod exit material temperature should be raised if this boil-off reduces the tie rod exit material temperature below 450°R.

(CRD) The pulse cooldown will be controlled by the following reactor temperatures:

a) A 450°R tie rod exit material temperature to terminate flow (this temperature should be raised on the basis of the observed extra cooling effect of the boil-off).

b) The pulse initiation control temperatures are: 850°R core station 1, 1300°R core station 20 or 26, 700°R reflector material temperature, and 780°R support plate temperature. (The core temperatures are 100°R below their test limits and the [illegible] component temperatures are 50°R below their test limits).

Pulse cooling will be utilized as long as it is required. The following table summarizes the total required quantity of liquid nitrogen and the end time for pulse cooling:

Operating Time at Rated Conditions (minutes)	30	45	60
Required Quantity of LN_2 (lbs)	93000	124000	153000
End of Pulse Cooling (hours after scram)	33	44	56
End of Pulse Cooling (seconds after scram)	118000	160000	200000

These cooldown predictions are based on the decay energy shown in figure 8-2, 900°R average nozzle chamber temperature during pulse cooling (approximate chamber temperature of NRX-A5 pulse cooldown), and 25 KW decay power (this condition corresponds to the power at the last pulse of the NRX-A5 EP-III cooldown).

TABLE 8-1

POWER DISSIPATION CAPABILITIES OF COOLANTS USED DURING COOLDOWN

Chamber Temperature, ^oR	1400		1200		1000		800	
Power	Power* MW	Equivalent Flow** (lb/sec)	Power* MW	Equivalent Flow** (lb/sec)	Power* MW	Equivalent Flow** (lb/sec)	Power* MW	Equivalent Flow** (lb/sec)
LH_2	5.17	1	4.44	1	3.70	1	2.97	1
GH_2 (540°R)	3.17	1.6	2.43	1.8	1.70	2.2	0.96	3.1
LN_2	0.44	11.8	0.39	11.4	0.33	11.2	0.27	11.0
GN_2 (540°R)	0.25	20.7	0.19	23.4	0.13	28.5	0.07	40.1

* Power in MW dissipated by a flow of 1 lb/sec of each coolant.

** Equivalent flow required to duplicate the heat removal capability of 1 lb/sec of liquid hydrogen.

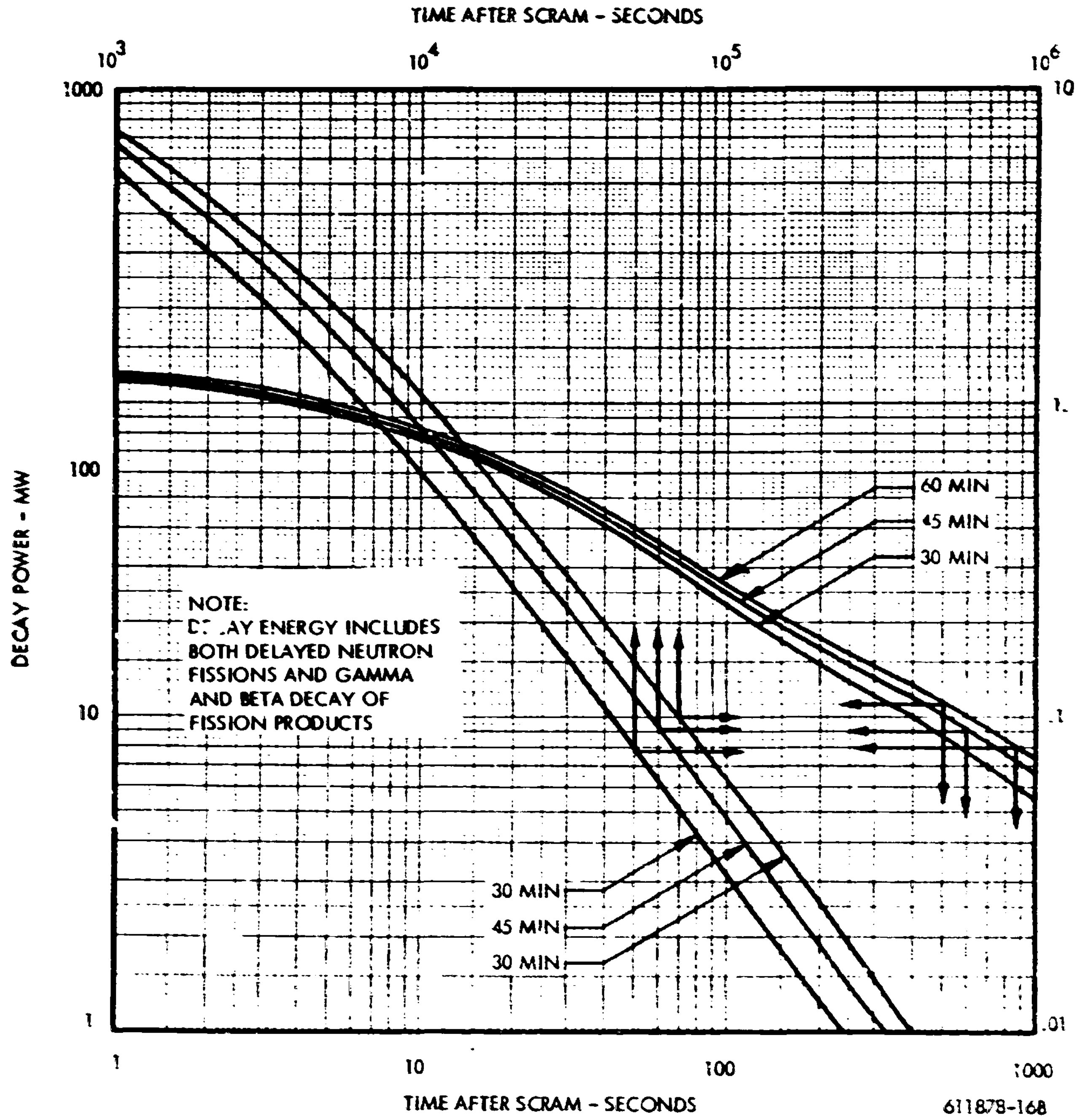

Figure 8-1. Total Decay Power after Scram for 30, 45 and 60 Minutes at Rated Conditions

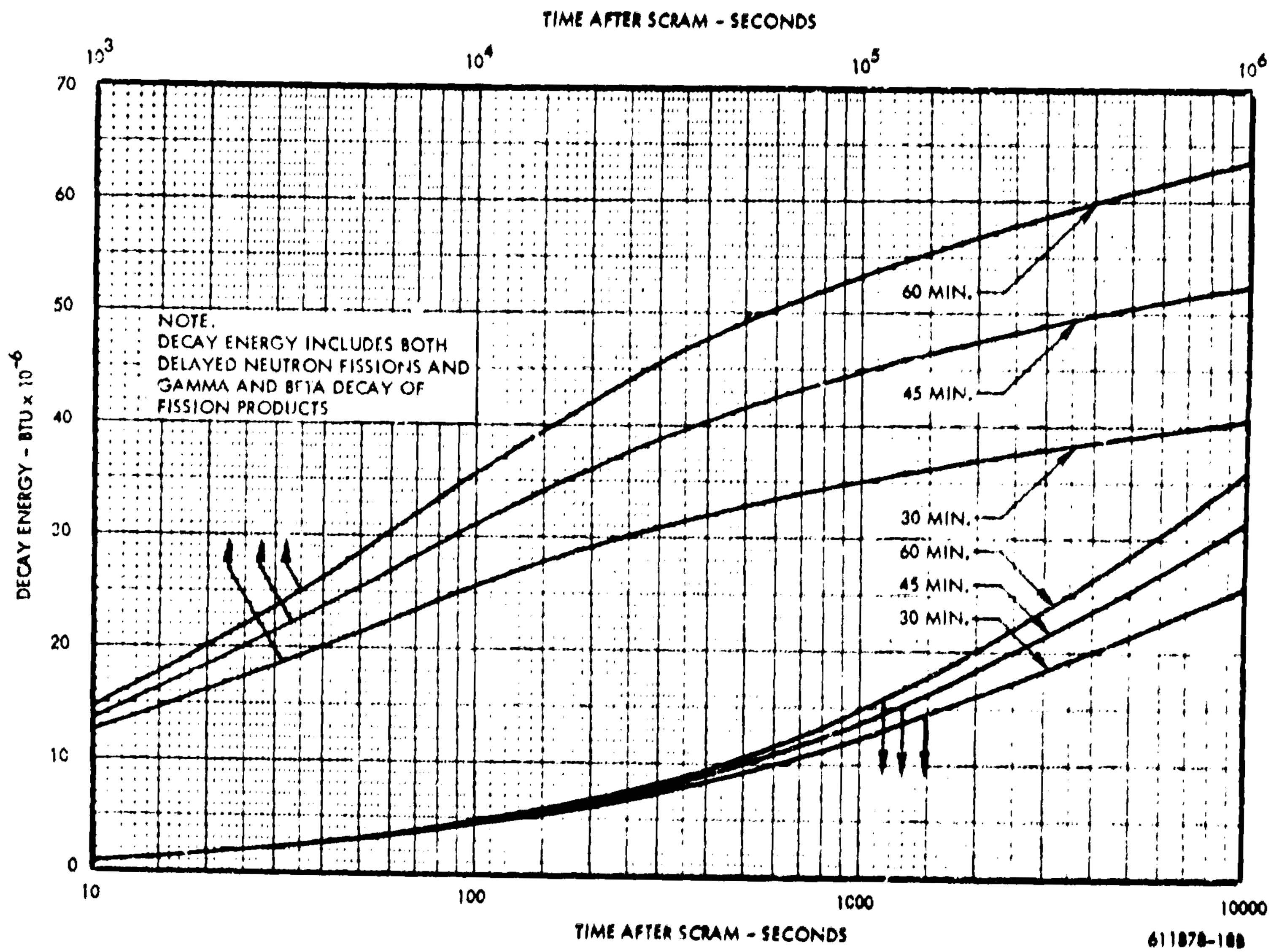

Figure 8-2. Total Decay Energy after Scram for 30, 45 and 60 Minutes at Rated Conditions

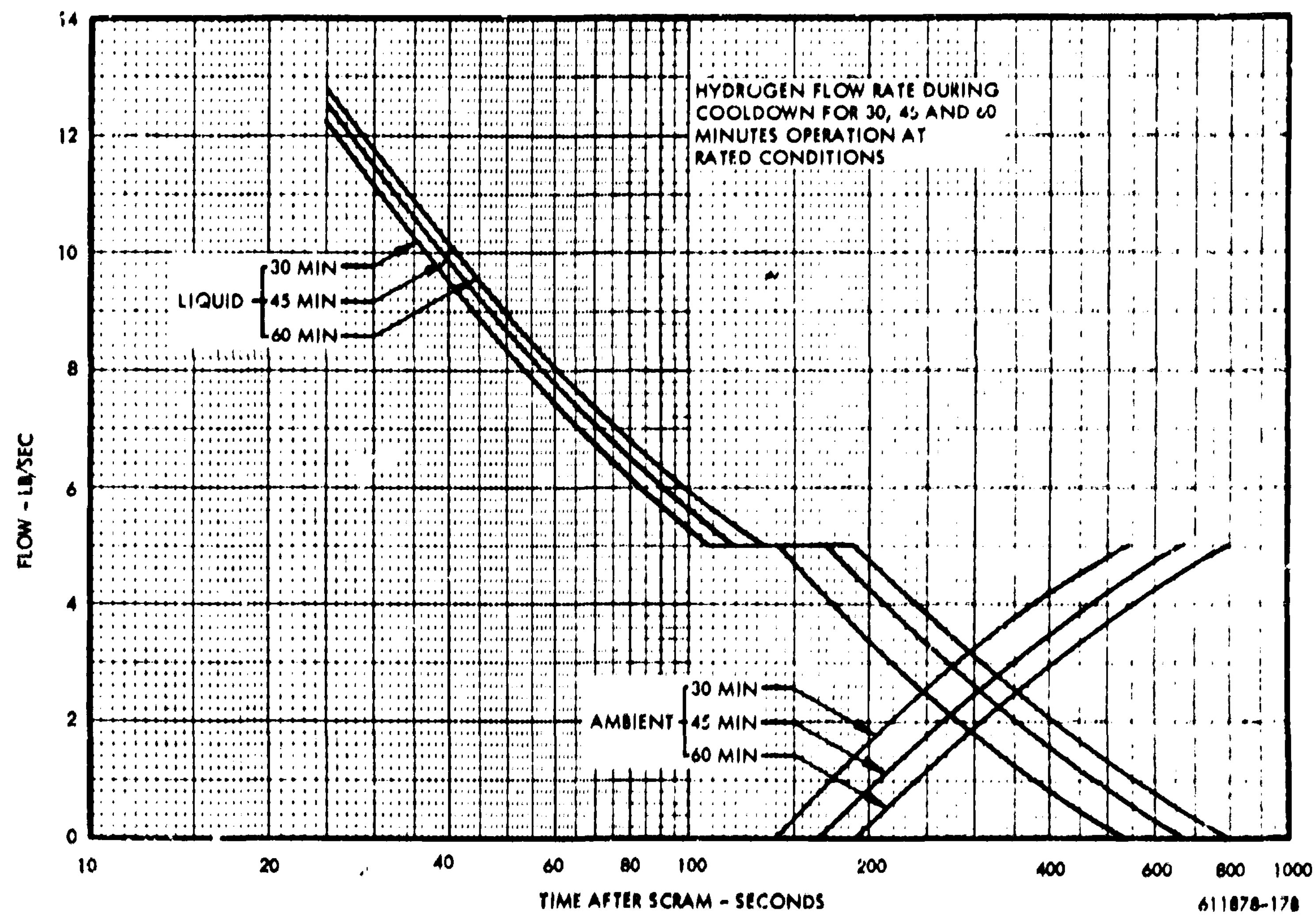

Figure 8-3. Hydrogen Flow Rate During Cooldown for 30, 45 and 60 Minutes Operation at Ruted Conditions

9.0 EMERGENCY SHUTDOWN

This chapter will be issued in a supplement at a later date after all emergency shutdown system parameters are finalized.

10.0 APPENDIX

10.1 Equations for Data Analysis

This section will be issued in a supplement

11.0 REFERENCES

1. WANL-TNR-215, "NRX-A6 Test Specification", September 1966 (and supplements)
2. WANL-TME-1642, "NRX-A6 Nuclear Subsystem Data Book", (to be issued)
3. WANL-TME-644, "NRX-A1 Test Predictions", January 1964
4. WANL-TME-887, "NRX-A2 Test Predictions", July 1964
5. WANL-TME-1050, "NRX-A3 Test Predictions", January 1965
6. WANL-TME-1211, "NRX-A4/EST Test Prediction", November 1965
7. WANL-TME-1388, "NRX-A5 Test Prediction Report", March 1966
8. WANL-TME-1629, "NRX-A6 Design Review", June 1, 1967
9. Letter, H. F. Faught to J. L. Dooling, "Transmittal of NRX-A6 Common Analog Model Equations Including High Pressure Dewar", January 25, 1967
10. WANL-TME-1556, "Test Cell "C" System Description Document", March 1967
11. WANL-TME-1592, "NRX-A6 Control System Description", May 1967
12. NTO-A-0029, Revision 1, "NTO Criticality Control Manual", I. P. Leggett, March 30, 1967
13. NTO-R-0075, "NRX-A5 Pre-Test Report", May 26, 1966
14. NTO-SOP-0017, "NTO Standard Operating Procedure for Neutron Multiplication Detection", Latest Revision.
15. WANL-TME-1403, "WANEF Critical Experiments in Support of NERVA Quarterly Report - Second Quarter CY '66", March 1966
16. WANL-TNR-219, "NRX-A5 Reactor Test Analysis Report", March 1967
17. LA-3441-MS, "Quarterly Status Report of LASL ROVER Program for Period Ending November 30, 1965", December 1965
18. "A Simple Technique for Estimation of the Reactivity Worth of Structures External to a NERVA Reactor", D. J. Hill, L. I. Ortenberg, D. A. McCutchan, Trans. Am. Nucl. Soc., 10, 1, pp. 9-10, June 1967
19. WANL-TME-1633, "NRX-A6 Safety Evaluation Report", to be published
20. WANL-TNR-216, "NRX/EST Reactor Test Analysis Report", December 1966
21. NTO-R-0084, "NRX-A5 Site Test Report", July 28, 1966

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Astronuclear Laboratory

22. MRL

23. CSE-FD-239, "Functional Design for the NRX-A6 Temperature Controllers", L. A. Demore, May 1967

24. CSE-FD-250, "Functional Design for the NRX-A6 Power Controller", L. A. Demore, May 1967

25. CSE-FD-251A, "Functional Design for NRX-A6 Power and Temperature Limiter", L. A. Demore, May 1967